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ENGINE/TRANSIMISSION/AIRFRAME ADVANCED INTEGRATION TECHNIQUES

Theodore Himka, et al

Boeing Vertol Company

Prepared for:

Army Air Mobility Research and Development Laboratory

May 1975

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ENGINE/TRANSMISSION/AIRFRAME ADVANCED INTEGRATION TECHNIQUES

Boeing Vertol Company
Boeing Center
P.O. Box 16858
Philadelphia, Pa. 19142

May 1975

Final Report

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distribution unlimited.

Prepared for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

This report provides an insight into various approaches that can be taken in aircraft design to integrate and manage external airflows so as to minimize ultimate vehicle performance penalty. In this case, stringent IR plume and hot-part suppression requirements greatly increased external airflows, adding to the complexity of the integration approach and dictating innovative design techniques. The aircraft performance penalties from the IR suppression requirements were reduced through improved integration techniques for various vehicle configurations. The results of this contract should be integrated in future vehicle studies and in the formulation of standard IR suppression criteria.

LeRoy T. Burrows of the Technical Applications Division served as project engineer for this effort.

Unclassified

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Innovative engine/transmission/airframe integrated design concepts were developed to provide total airflow and power management for a utility transport helicopter which meets projected requirements of future Army aircraft. These requirements include engine compartment cooling, drive train and transmission oil cooling, engine oil cooling, exhaust plume and hot metal infrared (IR) signature suppression, and engine inlet foreign particle protection.

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20. ABSTRACT (cont'd)

The baseline aircraft for the investigation was a single-main-rotor, twin-engine utility helicopter with a design gross weight of 8500 pounds. Following an initial review of six innovative designs, three propulsion integration concepts were selected for detailed preliminary design based upon comparative analyses and evaluations of overall system performance, system complexity, aircraft system weight and design, technical risk, and control requirements.

The integrated concepts each incorporated a mechanically driven blower to draw cooling air through the transmission oil cooler and into the IR suppressor device, which was integrated with the engine compartment cooling airflow and the particle separator scavenge.

The propulsion integration concepts achieved a much greater measure of protection against the IR missile threat than a current IR suppressor design on the baseline aircraft, which did not meet the suppression requirements established for this study. Also, reduced system complexity resulted from the integration of airflow requirements into one blower, as well as fewer individual transmissions in certain concepts. However, the penalties incurred were substantially more accessory (blower) power and a heavier weight empty, which served to reduce aircraft performance capability.

Scaled aircraft with integrated propulsion systems and engines scaled in power and weight to provide the same performance capability as the baseline aircraft would provide the desired IR suppression capability with a 15-percent increase in aircraft empty weight and a 22-percent increase in installed engine power.

SUMMARY

Under contract to the Eustis Directorate of the U. S. Army Air Mobility Research and Development Laboratory, the Boeing Vertol Company developed integrated engine/transmission/airframe conceptual designs for a utility helicopter to meet projected airflow requirements of future Army aircraft. The design program culminated in comparative analyses and evaluations of a baseline and six innovative concepts. Aircraft systems were evaluated on the basis of performance, weight, complexity and technical risk. This document is the final report of the aircraft design investigation.

BASELINE AIRCRAFT

The baseline aircraft selected for the conceptual analyses and preliminary designs was a single main rotor, twin-engine, utility helicopter, with a design gross weight of 8500 pounds, shown in Figure 1. Rotor system, structure, and materials utilized in the design were consistent with current design techniques as refined by 1980, and the drive system reflected state-of-the-art technology, proven by component demonstration. Suitable armor was provided for crew and critical component protection. Airframe ventilation and compartment cooling (including electronic equipment) was supplied by a separate fan, which was incorporated into the engine bleed-air pneumatic system for cockpit and cabin heating when required.

ENGINE CONFIGURATION

The advanced-technology turboshaft engines used in the study offered the alternative of front or rear drive, 30,000 rpm output shaft speed, and the capability of operating in either horizontal or vertical attitude. The engine included an integral inlet particle separator (IPS) and an integral lube system with a fuel-oil cooler. The engine was installed in a nacelle compartment to provide a continuous flow passage for cooling air, which was induced by an integrated engine exhaust-powered ejector.

The infrared (IR) suppression goal established for the engine exhaust plume was so rigorous and the resulting plume dilution requirement so great that it dictated an abundant amount of cooling airflow for IR suppression. Consequently, a design goal of 200°F metal temperature was established for the hot-metal IR suppressor. Suppressed signatures for the integrated propulsion system concepts were consistent with the following temperature levels:

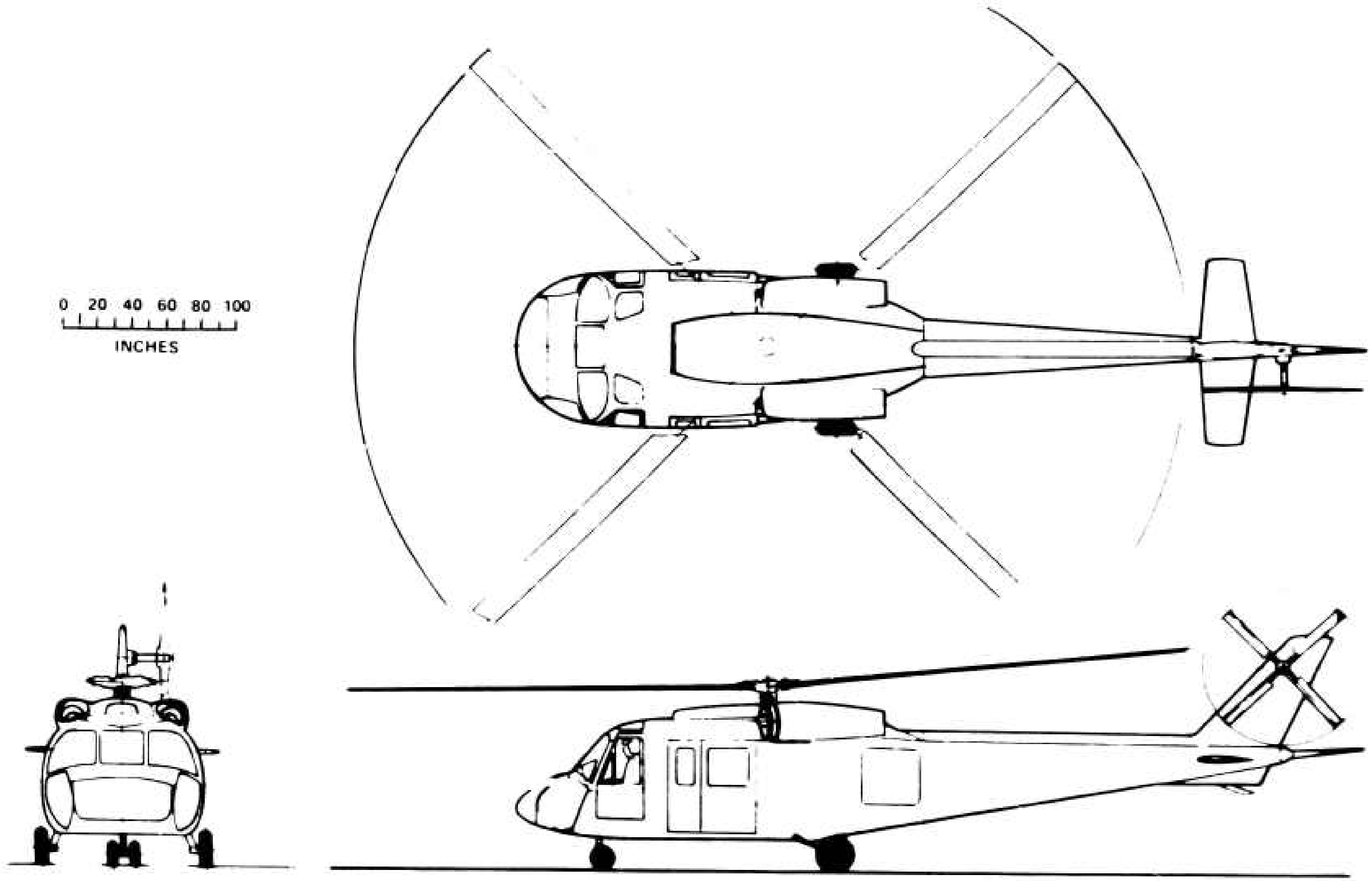


Figure 1. Baseline Utility Helicopter.

- o Hot metal temperature = 200°F
- o Exhaust plume temperature = 400°F

This level of IR suppression was provided over the entire flight spectrum.

INNOVATIVE CONCEPTS

In addition to the baseline aircraft with no IR suppression (Concept a), six advanced propulsion system concepts were identified for conceptual analyses. Design features of candidate concepts are outlined in Table 1. Airflows for the engine inlet and inlet separator scavenge, engine and drive train compartment cooling, transmission oil cooling, and IR suppressor were integrated in each advanced concept.

AIRCRAFT MISSIONS

Comparative analyses and evaluations of the different concepts were conducted for aircraft with a constant design gross weight of 8500 pounds. The range capability of the aircraft was defined based upon the mission noted below:

Extended Loiter Mission

1. HOGE, 15 minutes at 4000 feet, 95°F.
2. Cruise outbound to mission radius, 140 knots, at S.L., 59°F.
3. Loiter 1 hour, 70 knots, at S.L., 59°F.
4. Cruise inbound, 140 knots, at S.L., 59°F.
5. 30-minute reserve at 140 knots, at S.L., 59°F.
6. Entire mission flown with payload.

An alternative "Radius Mission" was postulated, flown entirely at 4000 feet, 95°F:

Short Loiter Mission

1. Warm up 2 minutes at maximum continuous power.
2. Cruise outbound to mission radius, 140 knots.
3. Land, unload payload.
4. Warm up 2 minutes at maximum continuous power.

5. Cruise inbound, 140 knots.

6. Reserve is 10 percent of initial fuel.

TABLE 1. CANDIDATE PROPULSION SYSTEM CONCEPTS

CONCEPT	BASELINE	HORIZONTAL, FRONT DRIVE	FAN-IN-FUSELAGE	VERTICAL, FRONT DRIVE	HORIZONTAL, REAR DRIVE	HORIZONTAL, DIRECT DRIVE	VERTICAL, REAR DRIVE
CONCEPT DESIGNATION	a	b	c	d	e	f	g
ENGINE							
Front Drive (F)	F	F	F	F			
Rear Drive (R)					R	R	R
ENGINE MOUNTING							
Horizontal (H)	H	H	H		H	H	
Vertical (V)				V			V
ANTITORQUE DEVICE							
Tail Rotor (TR)	TR	TR		TR	TR	TR	TR
Vectored Fan (VF)			VF				
INTEGRATED COOLING-FLOW CONCEPT							
Transmission-Driven Fan (X)				X		X	
Tail Rotor Shaft Fan (TR)		TR			TR		TR
Fuselage-Mounted Fan (F)			F				

ADVANCED-CONCEPT PRELIMINARY DESIGNS

Of the initial six propulsion integration concepts, a preliminary design was performed for three, selected on the basis of comparative analyses and evaluations of overall system performance, system complexity, aircraft system weight and design, technical risk, and control requirements. A detailed breakdown of the concept selection criteria and weighting factors is included in the text of the document. Selected advanced concepts are pictured schematically in Figure 2, and include the horizontal, front-drive engine concept; the vertical, front-drive engine concept; and the horizontal, direct-drive engine concept. In each concept a large fan, either concentric with the tail rotor shaft or driven from the main transmission, draws cooling air through the transmission oil cooler and pumps it into the suppressor device. Part of the cooling air used for plume dilution, in conjunction with the engine exhaust, provides the ejector action to ventilate the engine compartment and scavenge the inlet particle separator. The remainder of the cooling air provides hot metal cooling - the horizontal, front-drive engine concept uses a plug suppressor; the vertical, front-drive concept uses a vane-type suppressor; and the horizontal, direct-drive engine concept uses a vane-type suppressor followed by a jumbo-slot duct.

Each of the advanced concepts resulted in increased empty weight which impacted aircraft range capability, and each resulted in increased accessory power requirements which diminished vertical climb capability. The impact of a current IR suppressor design on weight and performance of the baseline configuration also was determined (designated Concept a'). Figure 3 compares the propulsion system and aircraft performance parameters for these designs.

> The concept with horizontal, front-drive engines had the lowest weight empty of the aircraft with integrated propulsion system installations, and offered good range capability but only moderate vertical climb capability. Engine-installation related factors in the aircraft system design compared favorably to the baseline aircraft.

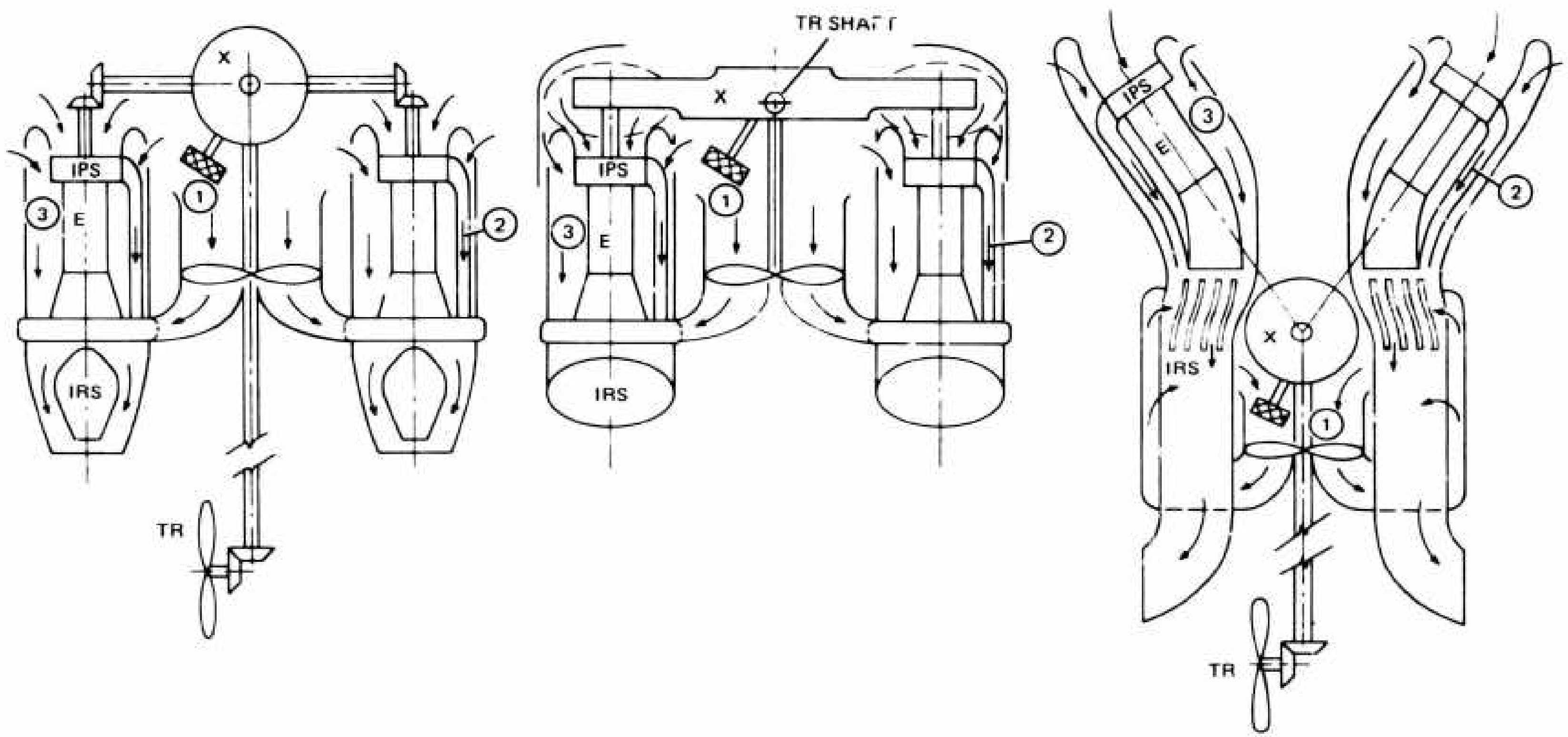


Figure 2. Schematic Drawings of Selected Propulsion-Drive System Integration Concepts.

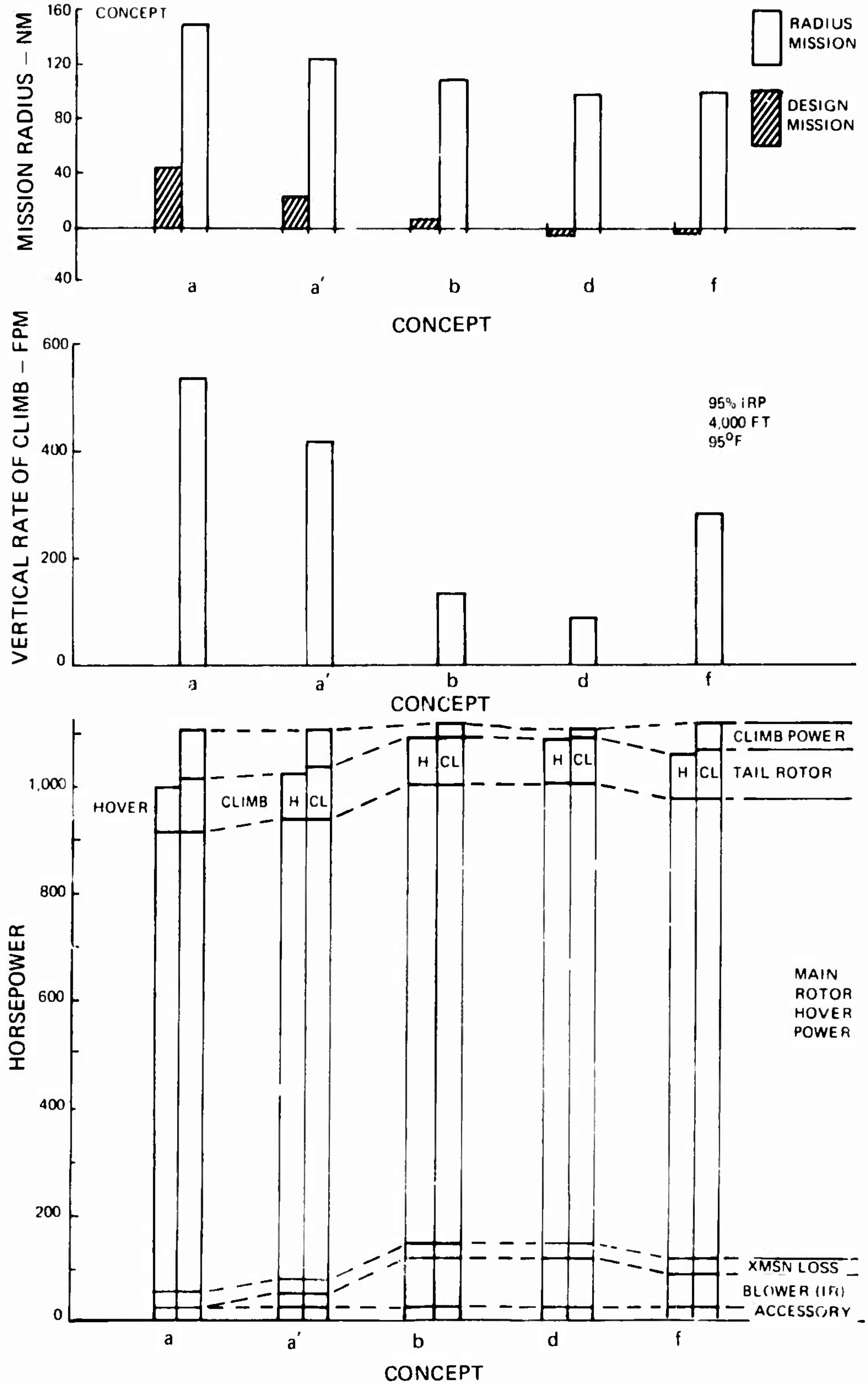


Figure 3. Propulsion System and Aircraft Performance for the Baseline and for Three Selected Advanced Concepts.

The vertical, front-drive engine concept had a larger weight empty and less installed power available due to engine inlet plenum losses. Although the aircraft had good range capability, its vertical climb capability was substantially reduced. Complexity was reduced significantly by elimination of engine transmissions and bevel-gear meshes in the drive train from engine to main rotor.

The horizontal, direct-drive engine concept also had a larger weight empty, but the installed power available was greater, so the aircraft had excellent vertical climb capability, although only moderate range capability. The direct drive into the main transmission from the rear-drive engines, without an engine-mounted transmission, contributed to reduced complexity of this concept.

The current IR suppressor design provided substantially less protection against the IR missile threat. Suppressed signatures for this design were consistent with the following temperature levels:

- o Hot metal temperature = 275°F
- o Exhaust plume temperature = 642°F

Figure 4 graphically illustrates the improved IR protection which the advanced concepts afford. Since aircraft system requirements dictated suppressed signatures much less than those obtainable by the baseline with a current suppressor design, the advanced propulsion integration concepts were necessary to achieve the desired IR protection. In addition, the advanced concepts offered improvements in IR suppression with less complexity than the baseline in terms of numbers of subsystems and components.

ADVANCED CONCEPT SELECTION

On the basis of the concept selection criteria discussed in the text of the document, there was very little difference among the advanced concepts in the total evaluation. While Figure 3 shows the superior range of the horizontal, front-drive concept and the superior climb capability of the horizontal, direct-drive concept, the reduced complexity of the vertical, front-drive engine concept compensated for its slightly poorer performance and made it virtually equal to the highest rated concept. Although cost was not considered in the study, qualitative evaluations of aircraft system life-cycle costs indicated that the vertical engine concept also

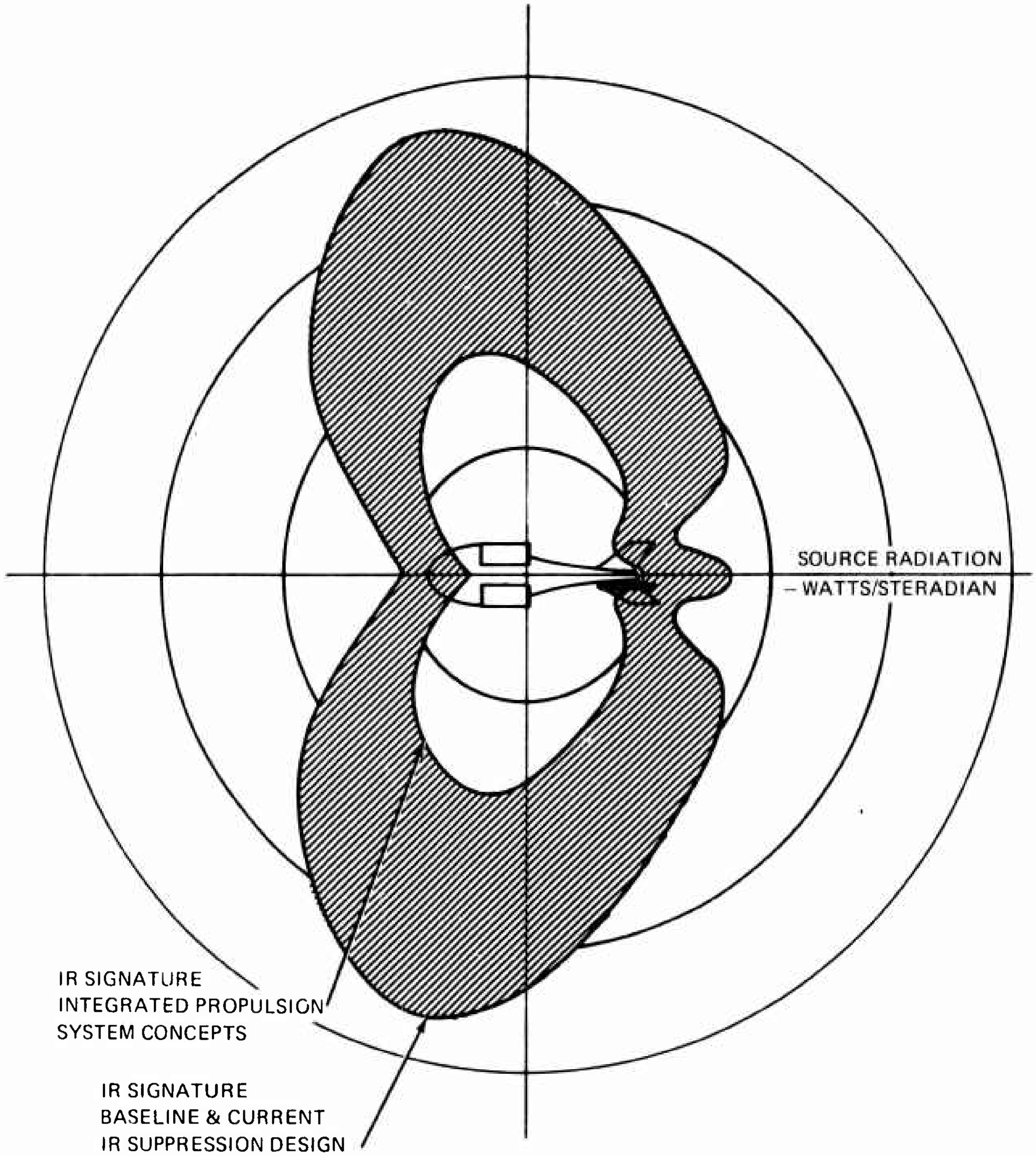


Figure 4. Improved IR Signature Suppression Provided by Integrated Propulsion System Concepts.

was the best in this regard. Research, development, test, and engineering (RDTE) cost factors are only a small percentage of the total life cycle cost of an aircraft system compared to production costs, which amount to slightly less than one-third, and operations and maintenance (O&M) costs, which comprise two-thirds of the life-cycle costs. Technical risk considerations and their impact on RDTE costs are relatively unimportant. Slight differences in aircraft empty weight for the advanced concepts, which would be reflected in production costs, make little difference in life cycle costs. But complexity and design factors, such as number of blowers, number of transmissions, number of bevel gear meshes, and engine accessibility, have the greatest impact on O&M costs and life-cycle costs. The vertical, front-drive engine concept was superior to the others in this respect, and is recommended as the best of the advanced concepts.

SCALED AIRCRAFT

It is of interest to compare the takeoff gross weight of aircraft scaled up in weight to perform the same mission and have the same climb capability, with engines scaled up in power and weight. Figure 5 compares "rubberized" versions of the baseline and the advanced concepts to meet the following performance requirements:

- 500-fpm vertical climb capability at 95-percent IRP (Intermediate Rated Power), 4000 feet, 95°F
- Design mission with 50-NM radius

There was little difference in gross weight among any of the advanced concepts.

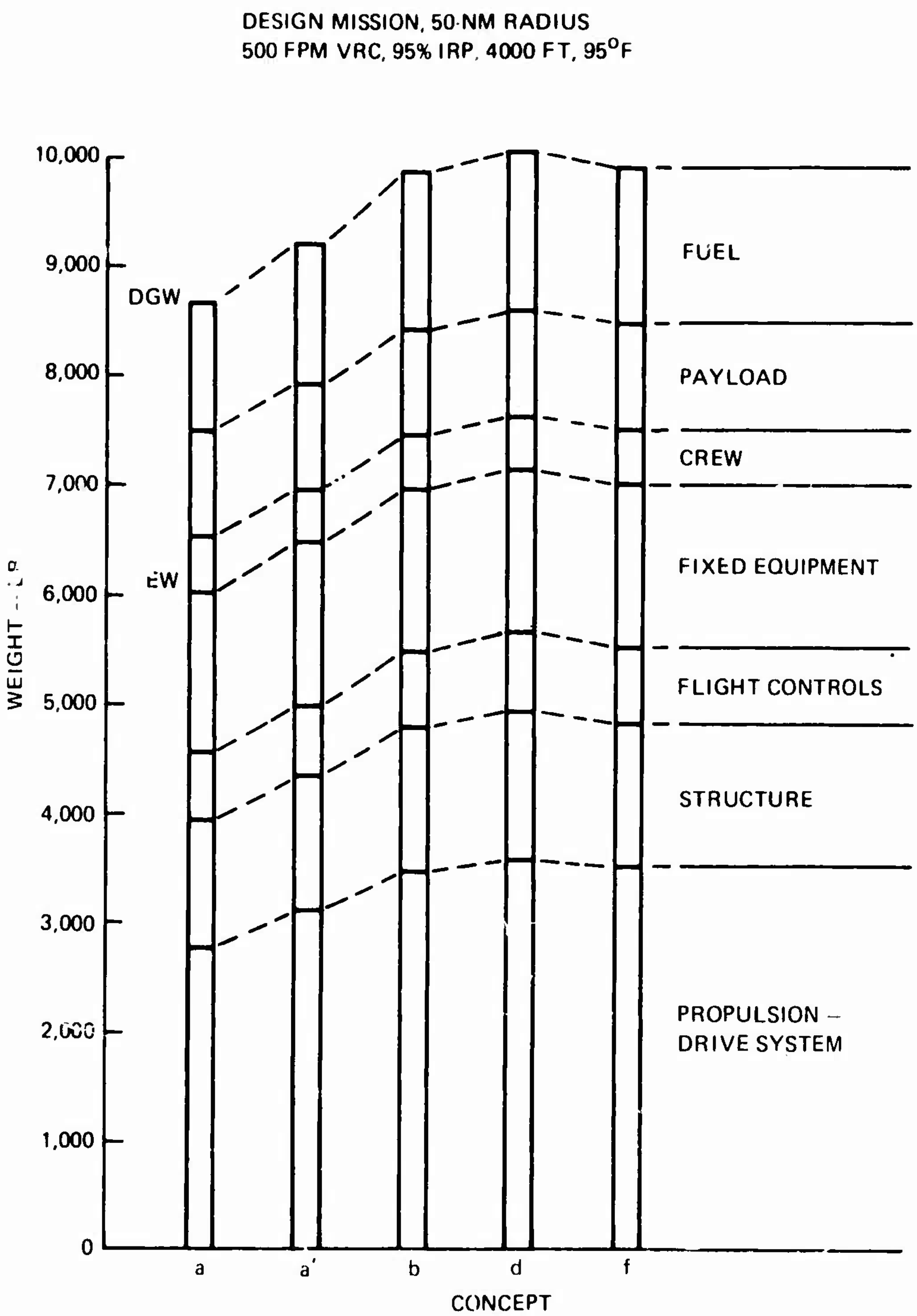


Figure 5. Scaled Aircraft Weight Comparison, Constant Range and Climb Capability.

PREFACE

This final technical report completes a 7-month design investigation of integration concepts which provide total airflow and power management to meet requirements of future Army helicopters. Boeing Vertol Company conducted the program under U. S. Army Air Mobility Research and Development Laboratory Contract DAAJ02-74-C-0043, Engine/Transmission/Airframe Advanced Integration Techniques.

Technical direction was provided by Mr. Leroy Burrows and Mr. James Gomez of the Technology Applications Division, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

INTRODUCTION

Propulsion system installations in future U. S. Army helicopters will be required to provide airflows for the following requirements:

- o Engine compartment cooling
- o Drive train and transmission oil cooling
- o Engine oil cooling
- o Infrared suppression (hot metal cooling and engine exhaust plume dilution)
- o Engine inlet particle separator (IPS) scavenging
- o Airframe ventilation (cockpit and cabin cooling)

In recent years increasing effort has been devoted to providing the proper environment for the propulsion and drive systems of military helicopters and to reducing their vulnerability, particularly as it depended upon the propulsion and drive systems. IPS kits have been developed for present-generation aircraft to provide engine-inlet protection from sand and dust contaminants. IR suppressor kits have been developed to provide suppression of the engine hot metal signature and, to a limited extent, suppression of the engine exhaust plume signature. Advanced turboshaft engines are trending to higher pressure ratios and turbine-inlet temperatures, and installation designs must provide cooling air for the accompanying high skin temperature and heat rejection. Integral oil systems with fuel/oil coolers are incorporated into some present-generation engines as well as into advanced-technology engines.

Integrated propulsion system concepts which provide efficient management of total airflow and power are needed to minimize installation complexity, cooling drag, and engine and transmission installation losses.

Under contract to the Eustis Directorate of the U. S. Army Air Mobility Research and Development Laboratory, the Boeing Vertol Company conducted a 7-month study of innovative engine/transmission/airframe integration concepts which provide total airflow and power management, to meet projected requirements of future Army aircraft. The objective of the work performed under this contract was to develop integrated design concepts for a utility transport helicopter including engine inlet foreign particle protection, exhaust plume and hot metal IR signature suppression, engine and transmission oil cooling,

engine compartment cooling, aircraft ventilation, and pylon boundary layer control to reduce drag. Six integrated concepts were initially presented and evaluated in comparison to the baseline aircraft propulsion system, and three were selected for preliminary design based upon the following considerations:

- Overall System Performance
- System Complexity
- Aircraft System Weight
- Aircraft System Design
- Technical Risk
- Control Requirements

AIRCRAFT SYSTEM REQUIREMENTS

Aircraft system requirements were established initially to provide the basis for the conceptual propulsion system designs and comparative analyses and evaluations. The helicopter configuration, design, mission, and payload were defined. State of the art of structures technology and drive system design were selected. Engine performance and weight, including an integral inlet particle separator, were established, and the required levels of engine hot metal IR suppression and exhaust plume dilution were stipulated.

BASELINE AIRCRAFT DEFINITION

The baseline aircraft selected for the conceptual analyses and preliminary designs was a single main rotor, twin-engine, utility helicopter, pictured in Figure 6. Rotor technology was based upon Boeing's YUH-61A and BO-105 helicopters. The hingeless, four-bladed, advanced-technology main rotor system used in the design incorporated advanced airfoils and composite materials. The rotor possesses a diameter of 40.92 ft and a solidity of 0.07.

A flex-strap tail rotor with an 8-foot diameter was selected to fulfill the antitorque requirement, and is impact resistant for safety, deiced for all-weather operations, and offers high capacity through the use of advanced airfoils. The vertical fin was designed to ensure level flight after complete tail rotor loss, and is deiced for all-weather operations.

The propulsion-drive system arrangement incorporated horizontal front-drive engines mounted parallel to each other, with engine transmissions to provide a right-angle bevel gear drive into the main transmission. The separated engine arrangement offers good survivability characteristics, since the separation between the two minimizes potential damage to both from a single projectile and also reduces secondary damage potential. In addition, engines which are separated from each other, the passenger compartments, and the fuel provide good safety and crashworthiness characteristics.

The main transmission of the baseline aircraft consisted of a spiral-bevel collector gear and a single planetary reduction stage. Use of only two stages of reduction results in a low main rotor transmission profile, which permits the aircraft to be loaded on the C-130 and C-140 without hub removal. A drive shaft extends from the main transmission to the intermediate transmission and another shaft to the tail rotor transmission, which drives the tail rotor.

Two accessory gearboxes, located fore and aft and driven by the main transmission, provide redundant electrical generators and hydraulic pumps for the aircraft subsystem requirements. The forward accessory gearbox (AGB) also incorporates a rotor brake. Mounted on the aft AGB is an integral oil cooler and blower unit which provides oil cooling capacity for the main transmission, both AGB's, and both engine transmissions.

Main engine starting is accomplished by batteries and an electrical starter, as discussed in the paragraph on the PROPULSION SYSTEM. Aircraft size, and particularly the small size of the main engines, precludes the use of an APU. Operating one main engine provides the facility of ground checkout of equipment and cockpit/cabin heating or ventilation.

The baseline aircraft does not possess an IR suppression system, although the impact of a current IR suppressor design on the baseline aircraft weight and performance was evaluated and is discussed in the section on DESIGN ANALYSIS.

Baseline Aircraft Sizing

A parametric sizing study was conducted to define the baseline aircraft to meet the system requirements stated below:

1. Single main rotor, twin-engine utility helicopter
2. Design gross weight (DGW) of 8500 pounds (desired)
3. Payload of 960 pounds (4 equipped troops)
4. Crew weight of 500 pounds (crew of 2)
5. Climb capability of 500 ft/min at 95 percent Intermediate Rated Power (IRP), 4000 feet, 95°F
6. Design mission (at Sea Level/59°F)
   - 15-minute hover
   - Cruise outbound at 140 knots
   - Loiter 60 minutes at 70 knots
   - Cruise inbound at 140 knots
   - 30-minute reserve at 140 knots
7. Two advanced-technology turboshaft engines with integral inlet particle separator (IPS), no IR suppressor, 1614 shp installed power available at sea level/ 59°F
8. Drive system technology consistent with the state of the art
9. Rotor system, structure, and materials technology as refined by 1980

The parametric trend data is displayed in carpet plot format as a function of disc loading, rotor tip speed, and mission radius in Figures 7 and 8. The trend data is based upon maintaining a constant thrust capability (C_T/σ) of 0.116 (at an advance ratio of 0.315) and a solidity of 0.073.

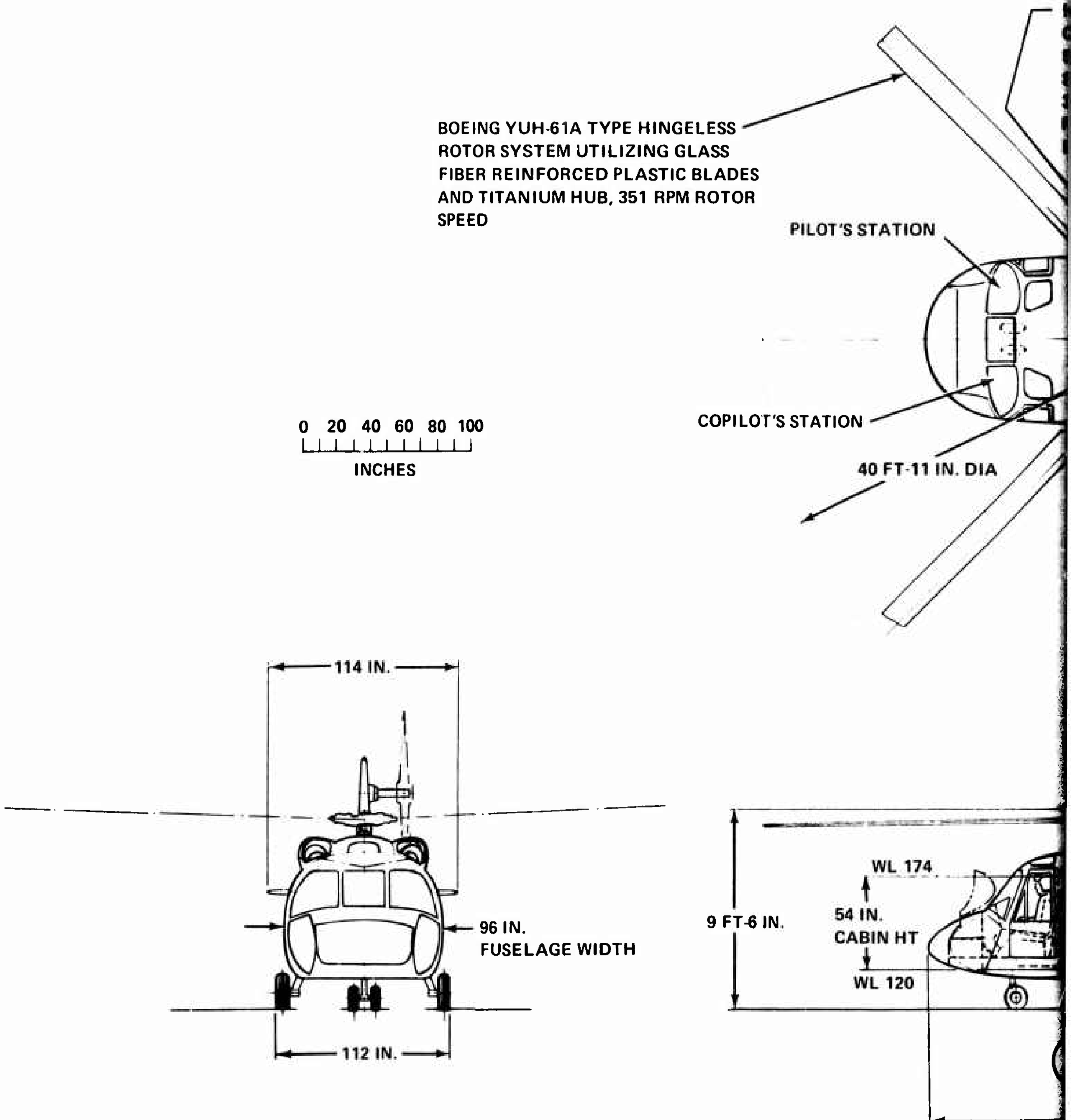
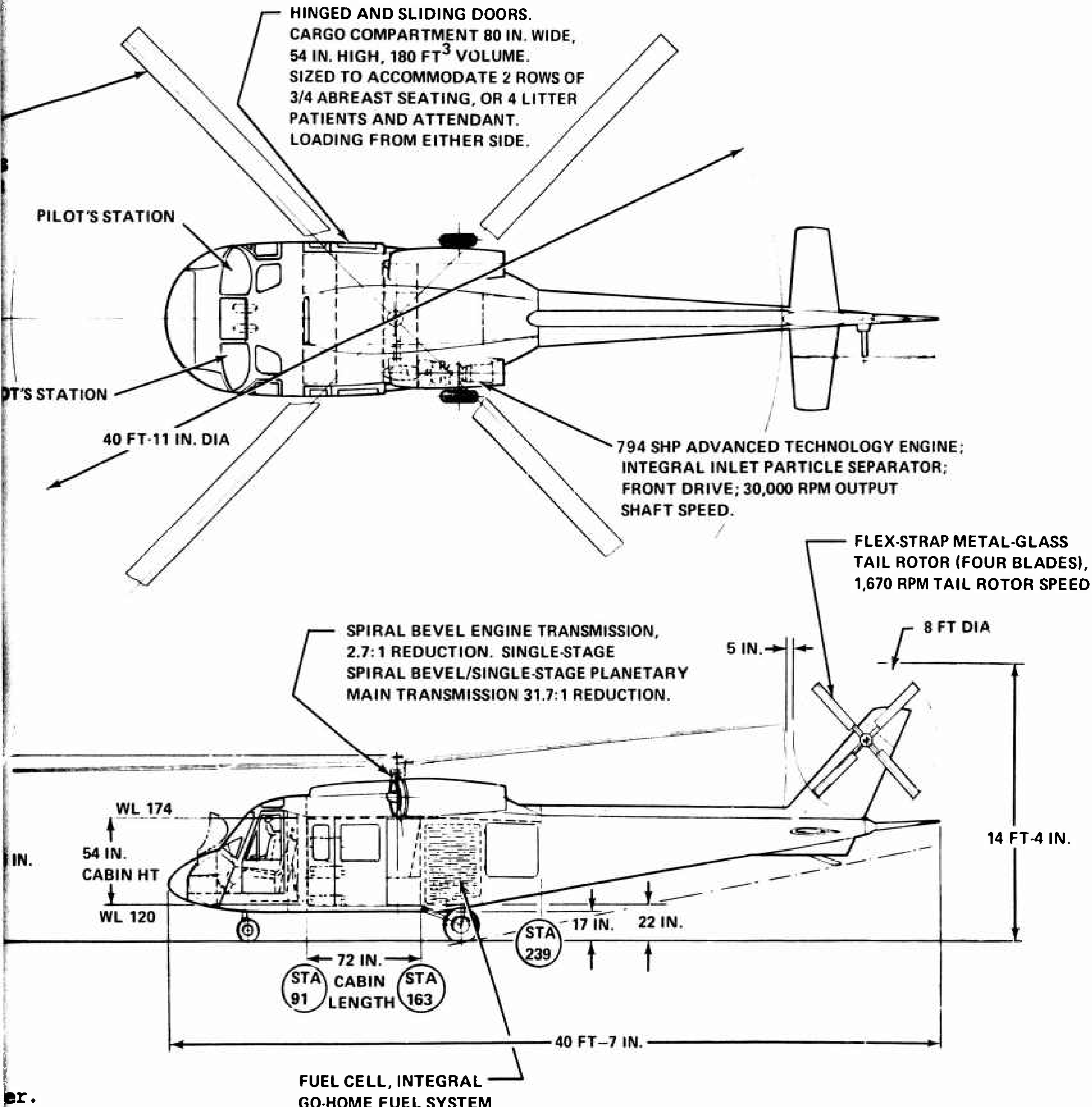


Figure 6. Three-View Drawing of Baseline Utility Helicopter.


HINGED AND SLIDING DOORS.
CARGO COMPARTMENT 80 IN. WIDE,
54 IN. HIGH, 180 FT^3 VOLUME.
SIZED TO ACCOMMODATE 2 ROWS OF
3/4 ABREAST SEATING, OR 4 LITTER
PATIENTS AND ATTENDANT.
LOADING FROM EITHER SIDE.
PILOT'S STATION
OT'S STATION
40 FT-11 IN. DIA
794 SHP ADVANCED TECHNOLOGY ENGINE;
INTEGRAL INLET PARTICLE SEPARATOR;
FRONT DRIVE; 30,000 RPM OUTPUT
SHAFT SPEED.
FLEX-STRAP METAL-GLASS
TAIL ROTOR (FOUR BLADES),
1,670 RPM TAIL ROTOR SPEED
SPIRAL BEVEL ENGINE TRANSMISSION,
2.7:1 REDUCTION. SINGLE-STAGE
SPIRAL BEVEL/SINGLE-STAGE PLANETARY
MAIN TRANSMISSION 31.7:1 REDUCTION.
5 IN.
8 FT DIA
WL 174
54 IN.
CABIN HT
WL 120
IN.
14 FT-4 IN.
17 IN.
22 IN.
STA 239
72 IN.
STA 91
CABIN LENGTH
STA 163
40 FT–7 IN.
FUEL CELL, INTEGRAL
GO-HOME FUEL SYSTEM

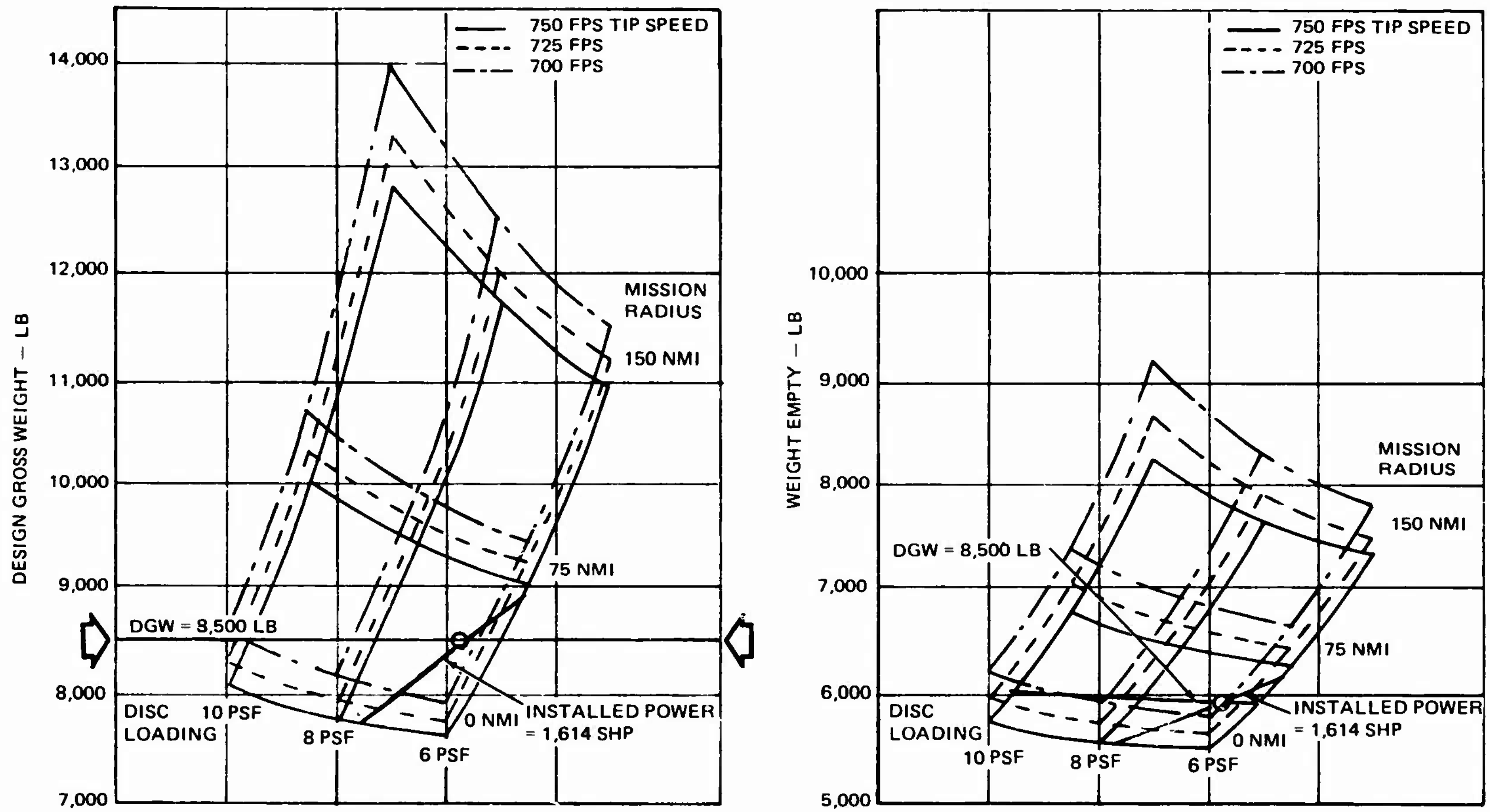


Figure 7. Parametric Study of Aircraft Gross Weight and Empty Weight as a Function of Mission Radius and Rotor Disc Loading and Tip Speed.

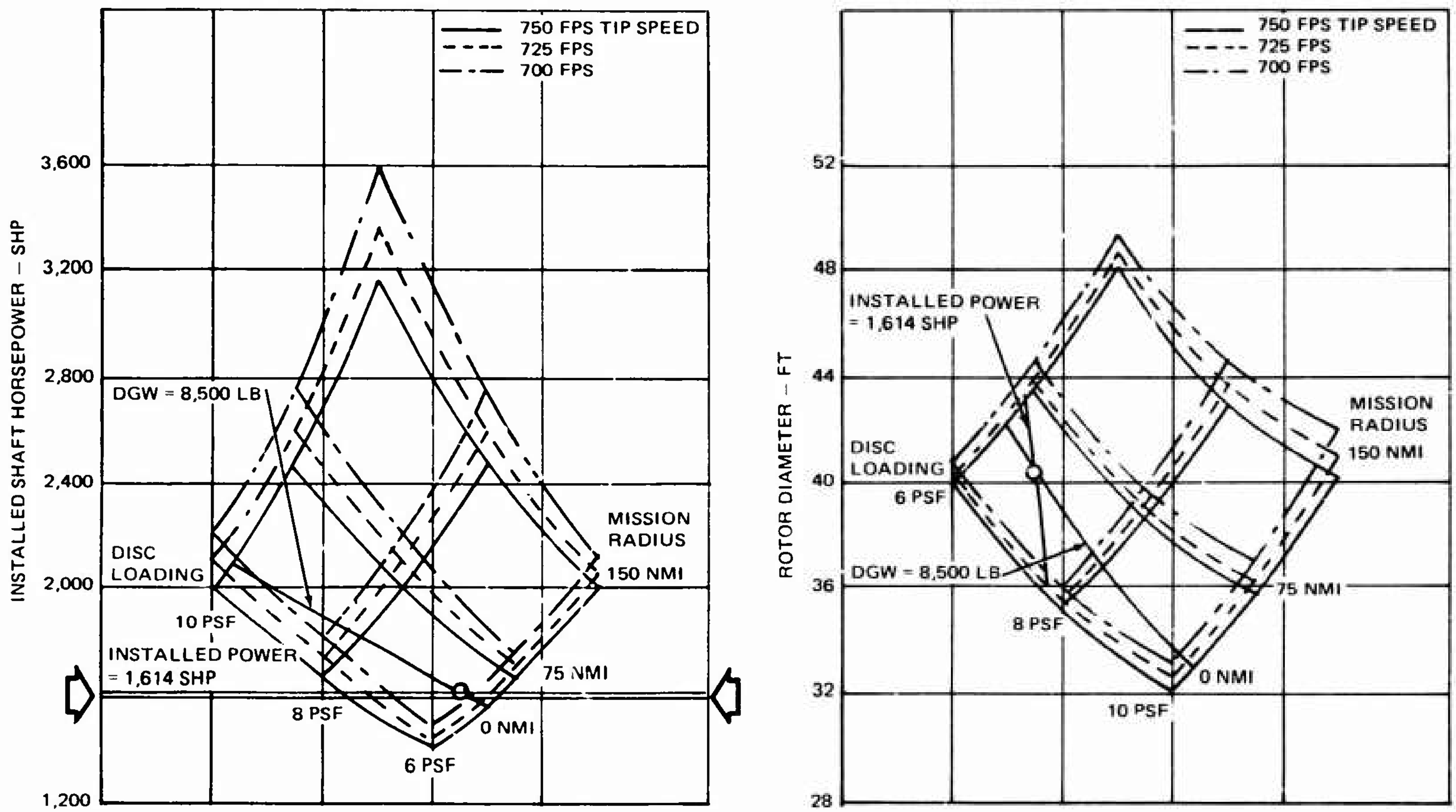


Figure 8. Parametric Study of Installed Shaft Horsepower and Rotor Diameter as a Function of Mission Radius and Rotor Disc Loading and Tip Speed.

Locus lines were developed on Figures 7 and 8 for a parametric family of 8500-pound gross weight aircraft and a parametric family of aircraft using the available installed power of 1614 shp. To avoid the confusion of a multiplicity of locus lines, only the lines for 750-ft/sec rotor tip speed have been indicated on the carpet plots.

Utilizing the constant DGW and installed shaft horsepower locus lines of Figures 7 and 8, Figure 9 was developed. As indicated, the main rotor diameter decreases with increased tip speed. Limiting the tip speed to 750 ft/sec dictates a main rotor diameter of 40 ft, 11 in.

A complete description of the baseline aircraft is provided in Tables 2 and 3, which list size and weight data by subsystem.

Materials and Weight Trends

The technology level of the rotor system, structures, and materials of the baseline aircraft is consistent with current design techniques as refined by 1980. Studies were conducted to determine where advanced composite materials could be employed in structure and fairings. During the structural design investigation, advanced structural techniques were defined which utilized the latest analytical, material, and fabrication technology for significant vehicle weight reductions without sacrificing structural efficiency, fail-safety, safety and producibility. These initial studies showed a possible reduction of 25% in the vehicle weight by the use of advanced composites in the 1980 time period.

The reduction in weight could be realized in the following areas:

Body	15 percent reduction
Horizontal Tail	21 percent reduction
Engine Section	12 percent reduction
Landing Gear	13 percent reduction
Advanced Aircraft Structure	25 percent reduction

However, for the purpose of this study, a weight reduction of only 15 percent was assumed to minimize program risk.

Figure 10 shows an exploded view of the advanced aircraft major structures and those items scheduled for the weight reduction as refined in 1980. The major items that contributed to the weight decrease of the advanced aircraft were as follows:

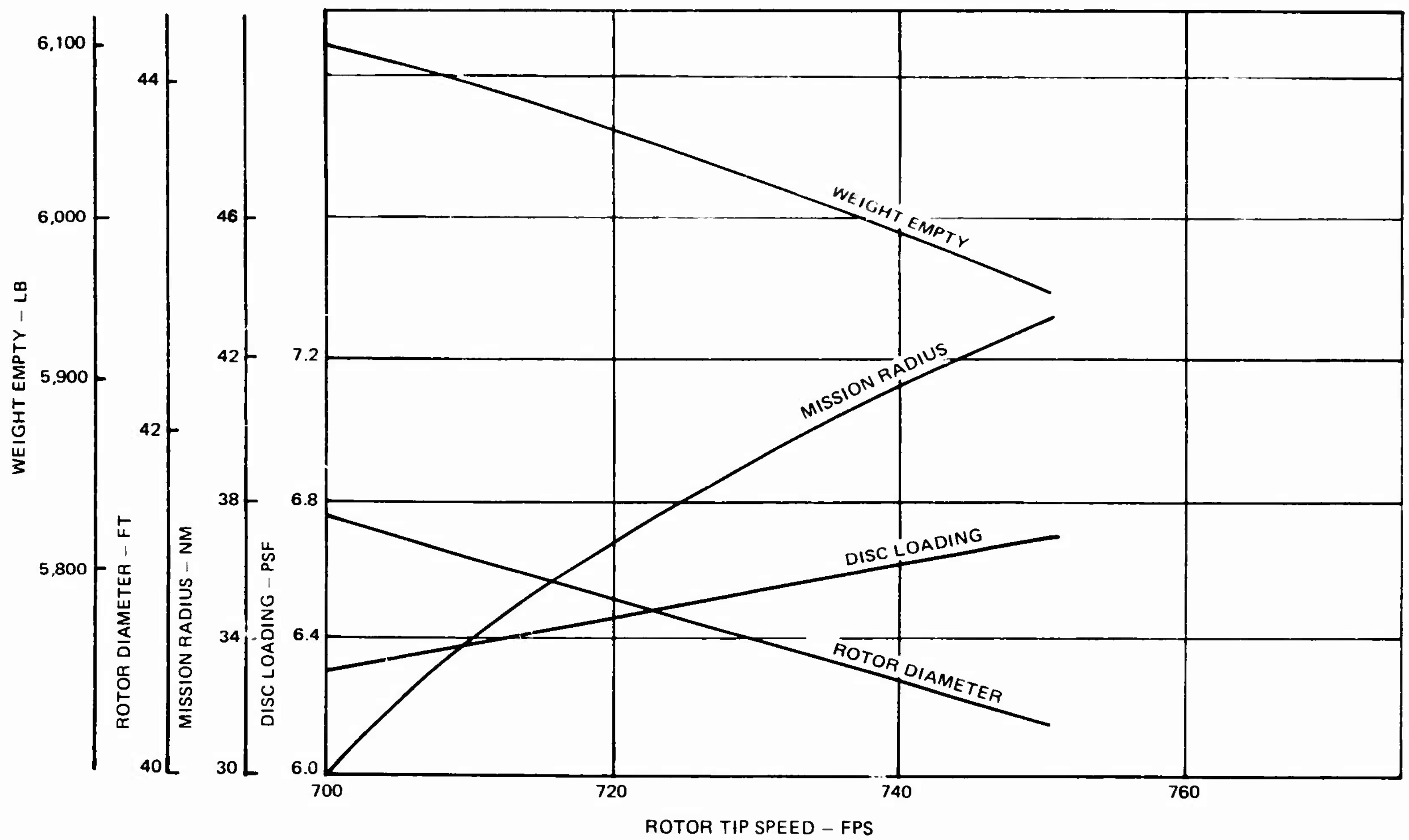


Figure 9. Parametric Study Results for 8500-Pound DGW and 1614-SHP Installed Power.

TABLE 2. BASELINE AIRCRAFT DIMENSIONAL AND PERFORMANCE DATA

Aircraft Subsystem	Dimension/Performance
Fuselage	
Length (Body & Tail Boom), ft	41.6
Length (Cabin), ft	9.2
Length (Body), ft	20.1
Length (Tail Boom), ft	21.5
Fwd. Rotor Location, ft	12.6
Width, ft	8.0
Wetted Area, sq ft	492.1
Horizontal Tail	
Aspect Ratio	5.700
Area, sq ft	20.8
Span, ft	10.9
Mean Chord, ft	1.9
Taper Ratio	0.566
Thickness/Chord	0.150
Hor. Tail Arm, ft	21.7
Vertical Tail	
Aspect Ratio	1.722
Area, sq ft	19.2
Span, ft	5.7
Mean Chord, ft	3.3
Taper Ratio	0.473
Tail Rotor (Vert.) Location, ft	4.0
Tail Rotor/Vert. Tail Overlap Ratio	0.563
Thickness/Chord	0.230
Main Rotor Pylon	
Aspect Ratio	0.100
Wetted Area, sq ft	18.3
Frontal Area, sq ft	4.4
Height, ft	0.8
Mean Chord, ft	8.3
Taper Ratio	1.000
Root Thickness/Chord	0.270
Tip Thickness/Chord	1.000
Main Rotor	
Diameter, ft	40.9
Solidity	0.073
Disc Loading, lb/sq ft	6.5
Thrust Coeff./Solidity	0.116
No. of Rotors	1.
No. of Blades/Rotor	4.
Blade Twist, deg	-12.000
Blade Cutout/Radius Ratio	0.230
Tip Speed, ft/sec	750.
Tail Rotor	
Diameter, ft	8.0
Solidity	0.159
Net Disc Loading, lb/sq ft	10.3
Thrust Coeff./Solidity	0.0
No. of Blades/Rotor	4.
Blade Twist, deg	-9.000
Blade Cutout/Radius Ratio	0.250
Main/Tail Rotor Gap, ft	0.5
Tip Speed, ft/sec	741.

TABLE 3. BASELINE AIRCRAFT WEIGHT DATA

Aircraft Subsystem	Weight, lb		
Propulsion Group			
Total Main Rotor Group		888.	
Main Rotor Blade (Per Rotor)	492.		
Main Rotor Hub (Per Rotor)	396.		
Drive System		923.	
Primary Engines		430.	
Primary Engine Installation		261.	
Fuel System		172.	
Total Propulsion Group Weight			2675.
Structures Group			
Tail Group		75.	
Hor. Tail	35.		
Tail Rotor	40.		
Fuselage		837.	
Landing Gear		245.	
Nose Gear	55.		
Main Gear	190.		
Total Structure Weight			1157.
Flight Controls Group			
Primary Flight Controls			
Cockpit Controls	48.		
Main Rotor Controls	255.		
Main Rotor Systems Controls	237.		
Fixed Wing Controls	3.		
SAS	35.		
Total Flight Controls Group Weight			592.
Weight of Fixed Equipment			1483.
Weight Empty			5907.
Fixed Useful Load			506.
Operating Weight Empty			6413.
Payload			960.
Fuel			1127.
Gross Weight			8500.

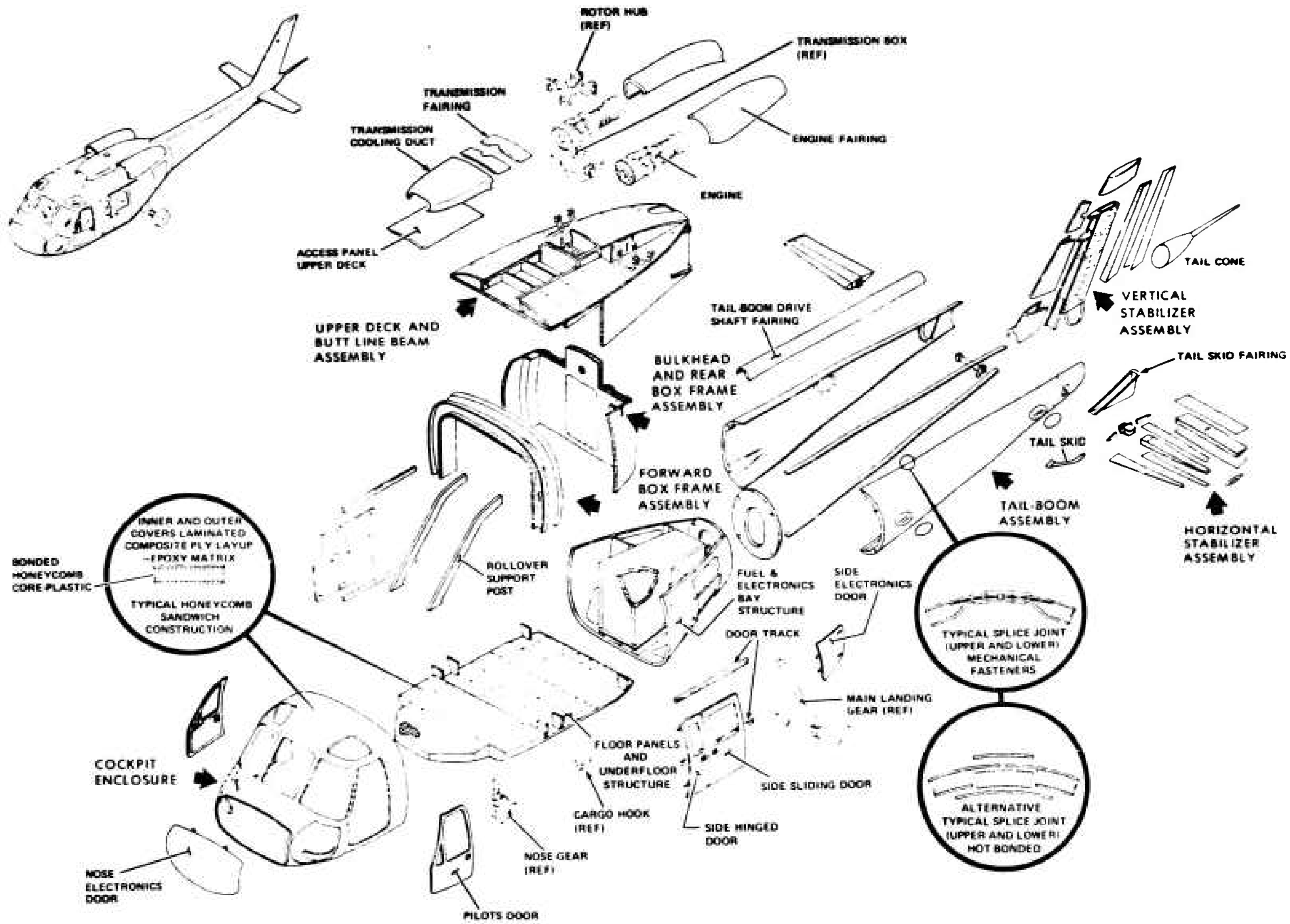


Figure 10. Subsystem Structural Components Utilizing Advanced Composite Materials to Achieve Weight Reduction.

- Cockpit Enclosure was composed of composite honeycomb sandwich molding (sandwich fiberglass) with integral reinforced side post flanges and plastic core epoxy matrix. The unit was a one-piece molding, or in two halves with a vertical splice.

- Doors consisted of a composite honeycomb sandwich of fiberglass with molded composite close-out members around door edges.

- Floor panels were a plank configuration made in composite honeycomb sandwich (graphite-epoxy), which were mechanically attached to an underfloor structure of an "egg crate" arrangement. Floor also consisted of continuous longitudinal floor beams with intercostal frames of composite honeycomb sandwich construction.

- Upper Deck structure was formed by a composite honeycomb sandwich (graphite-epoxy) horizontal deck panel, canted at its rear end, combined with two deep buttline beams of the same construction attached to the rear underside of deck, with matching continuous beams running longitudinally along upper surface of deck.

- Engine Fairings were thin honeycomb sandwich composite (graphite-epoxy) molding.

- Tail Boom Assembly structure was a two-piece clamshell construction with molded honeycomb sandwich (graphite-epoxy), requiring only end frames for stabilization. This assembly consisted of a molded honeycomb sandwich frame at the forward end and canted banjo-type one-piece frames of same design located in line with vertical stabilizer front and rear spars. Upper and lower splice joints are either hot bonded or mechanically fastened.

- Horizontal Stabilizer was a full-depth honeycomb core with composite (fiberglass) skins and flat tapering spar caps running spanwise and overlapping a titanium root end fitting with tapering flat prongs. A detachable leading edge nose skin was of thin honeycomb design. Post end and tip ribs were of a conventional aluminous alloy design and bonded to skin and core (graphite-epoxy) structure. A four-bolt lug system enables the stabilizer to be folded, if need be, for transportability.

- Vertical Tail was a one-piece torque box section of composite honeycomb sandwich (boron epoxy), formed by an inner skin with integral unidirectional cap material molded over inflated-type mandrel. Honeycomb core sheets were hot molded and wrapped over the inner skin.

Separate flanged molded channels matching front and rear spar widths were bonded to spars and banjo frames in tail boom, to join stabilizer to tail boom.

- <u>Landing Gear</u> construction utilized metal matrix and/or epoxy matrix in the drag struts and oleo barrels, pistons, etc.

Valuable weight and layup time can be saved by integration of high and low modulus materials in hybrid (mixed system) sandwich skins. In addition, the use of hybrid sandwich skins satisfies strength and stiffness requirements while providing improved impact resistance, fail-safety, ballistic tolerance and crash attenuation. Weight savings realized from the use of composite materials are summarized in Table 4, which shows the actual percent weight reduction used in the study.

Armor Requirements

Suitable armor was identified in the aircraft configuration design to provide protection for crew and critical components against 7.62-mm projectiles. This criterion for armor protection is consistent with that used in Boeing's YUH-61A UTTAS helicopter.

Protection of the aircraft against a 23-mm threat would entail a large increase in weight empty for adequate armor. Decreased vulnerability through careful consideration in design was judged to be a more desirable approach, since armor protection against the larger projectile threat would have a major impact on study results.

Ventilation and Cooling Requirements

The environmental control system provides the heating and ventilation, cooling and thermal control for the cockpit and cabin, avionics, and other equipment in the crew compartment consistent with system requirements. An electric fresh air fan provides ambient air for compartment ventilation (both cockpit and cabin) in the absence of a heating demand. The fan and associated ducting direct the air into the cockpit or cabin, rather than sucking air from inside the aircraft. Compartment heating is provided by bleed air from the main engine. Sufficient bleed air is available to meet this requirement.

TABLE 4. WEIGHT REDUCTION THROUGH USE OF COMPOSITE MATERIALS

	POTENTIAL REDUCTION (Percent)		MATERIAL*	ACTUAL REDUCTION USED IN STUDY (Percent)
HORIZONTAL TAIL	21			15
BASIC STRUCTURE		36	GR/EP	
L.E. & T.E. SKIN		20	PRD-49	
BODY	15			15
COCKPIT ENCLOSURE		20	S. GLAS	
SKINS & STRINGERS		20	GR/EP	
DOORS		35	PRD-49	
TAIL BOOM		25	GR/EP	
FLOOR		10	GR/EP	
DECKS		10	GR/EP	
V. TAIL STRUCTURE		35	BO/EP	
V. TAIL - L.E. & T.E.		20	PRD-49	
LANDING GEAR	13			10
STRUCTURE		19	GR/EP	
ENGINE SECTION	12			10
ENGINE MOUNTS		10	BO/AL	
NACELLE STRUCTURE		20	GR/EP	
DOORS, ETC.		35	GR/EP	
DUCTS		36	GR/EP	

*MATERIALS:

GR : Graphite
EP : Epoxy
BO : Boron
AL : Aluminum
PRD-49 : Fiberglass
S. GLAS: Sandwich Fiberglass

DRIVE SYSTEM

The baseline aircraft incorporates a current state-of-the-art drive system patterned after the YUH-61A UTTAS. Technology differences between the baseline and the advanced concepts were primarily in the propulsion system installations, specifically the main transmission and the overrunning-clutch designs. These differences were based upon proven engineering designs substantiated either in service or by test.

The baseline drive system configuration incorporates engine nose gearboxes with a right-angle drive into the main transmission, which consists of a spiral bevel collector gear and a single planetary reduction stage. The baseline configuration offers the advantages of the overrunning clutch, located on the low-speed shaft which provides good reliability. In addition, the spiral bevel collector gear and single-stage planetary main transmission represent a low-weight, low-risk installation. The propulsion-drive system installation of the baseline aircraft is pictured in Figure 11.

Transmissions

The engine nose gearbox, directly mounted to the engine, provides a short, accurately aligned, completely contained installation of the high-speed (30,000 rpm) engine output shaft. A single spiral bevel mesh in this transmission permits the clutch to be located on the lower speed shaft and integral with the nose gearbox. The clutch is a sprag-type clutch, designed to overrun for at least 30 minutes after loss of all oil.

The collector gear of the main transmission is attached to the sun gear of a single planetary gear stage. The main transmission housing is an aluminum forging.

A prime lubrication system and a backup system were considered for all configurations, with pumps and tanks armored against 7.62-mm projectiles and designed to minimize damage due to 12.7-mm and 23-mm HEI projectiles.

The drive systems for each of the advanced concepts, although differing in design from the baseline, incorporated current technology with design refinements that can be expected by the 1980 time period.

Transmission Oil Cooler/Blower

Investigations undertaken by Boeing Vertol indicated the reduced vulnerability and improved cost effectiveness of an annular type integral oil-air cooler for helicopter transmissions. A subsequent development program demonstrated the feasibility and practicality of the annular oil cooler concept. The results of the latter program are reported in Reference 1. The development hardware weighed 26.4 lb (16.2-lb heat exchanger core and 12.2-lb blower) and the cooler produced 2340 Btu/min, which exceeds the present study aircraft requirements. This integrated cooler/blower concept provided the following advantages:

- Improved survivability
- Increased cooling effectiveness
- Cost effectiveness
- Excellent vibrational characteristics

The transmission losses for the baseline aircraft and advanced concepts, discussed in the paragraph on Transmission Losses and calculated in Appendix A, were 1285 Btu/min. Consequently, for this application heat exchanger core and blower were scaled down from the developed hardware to 12.0 lb and 6.0 lb, respectively.

The integral oil cooler/blower concept as used in the study is consistent with the state of the art as proven by the referenced component demonstration, and suitable for a 1980 aircraft.

Accessory Gearboxes

The propulsion system installation incorporated two accessory gearboxes, separated fore and aft of the main transmission, to provide redundancy in subsystem power supply and so improve aircraft survivability. On each of the accessory gearboxes

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(1) A. J. Lemanski and H. J. Rose, INVESTIGATION OF AN EXPERIMENTAL ANNULAR-SHAPED INTEGRATED TRANSMISSION OIL COOLER DESIGN, The Boeing Company, Vertol Division; USAAVLABS Technical Report 70-41, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, September 1970, AD875985.

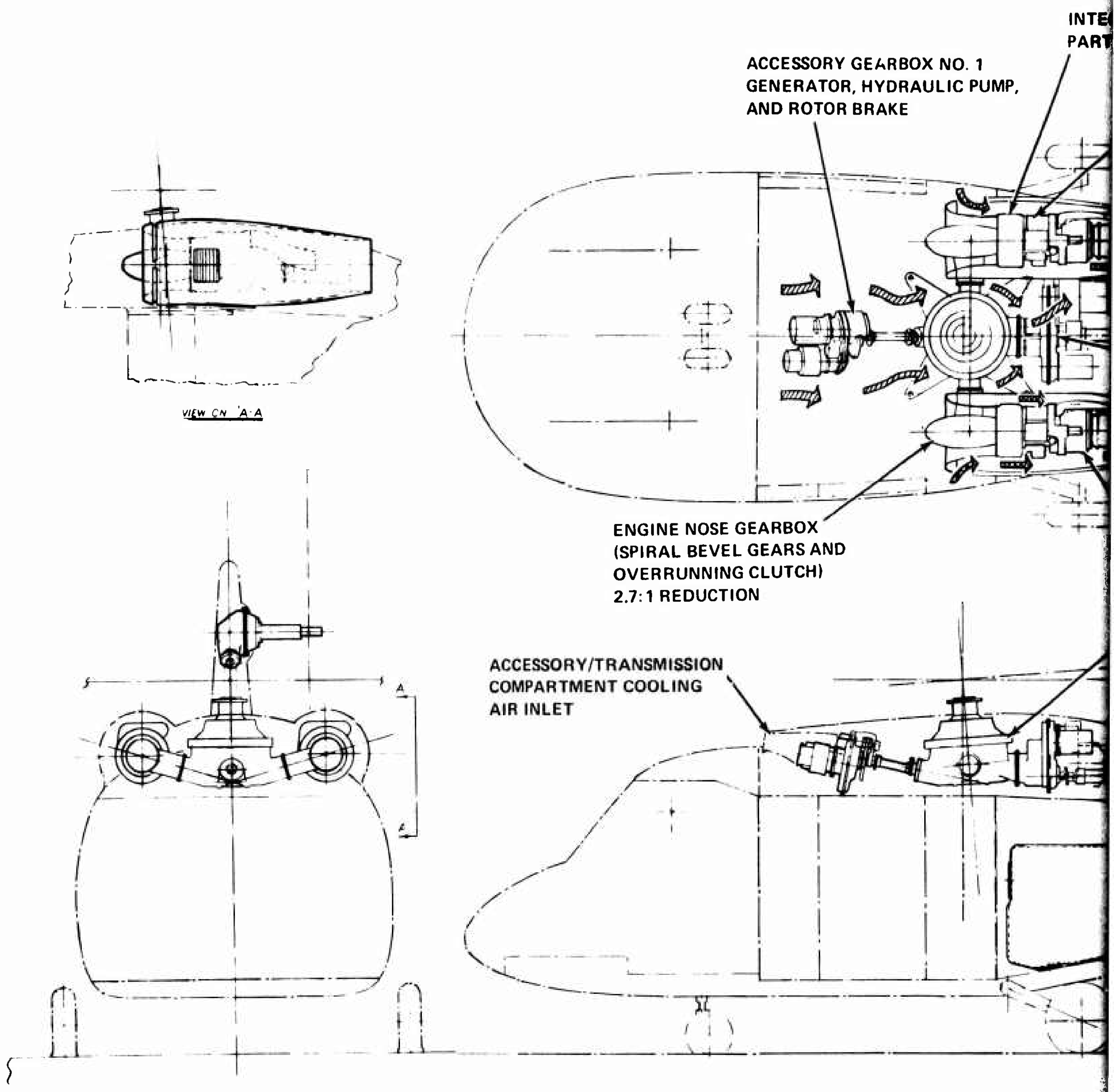
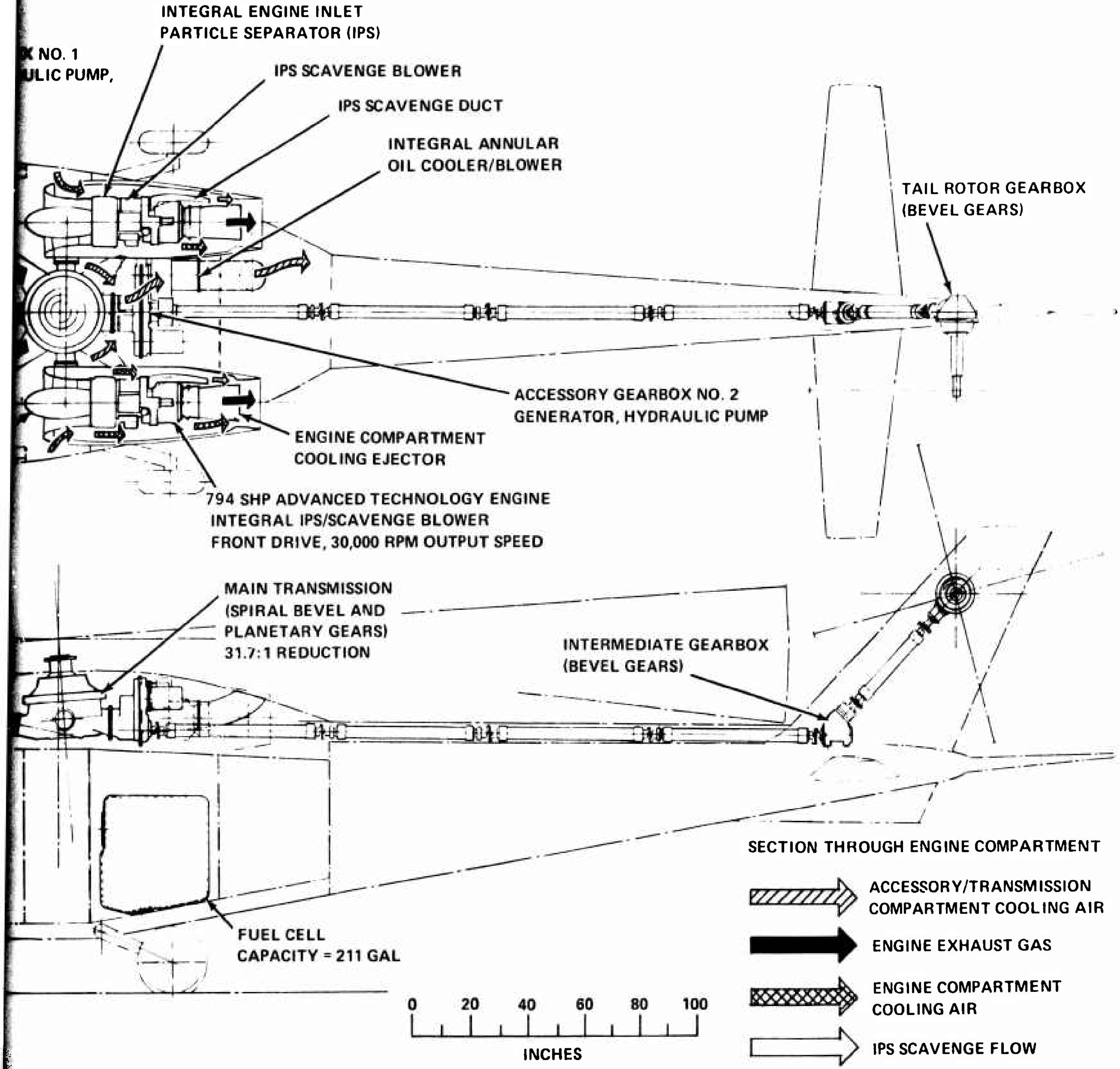


Figure 11. Concept a, Baseline Aircraft Propulsion-Drive System Conceptual Design.


INTEGRAL ENGINE INLET
PARTICLE SEPARATOR (IPS)
X NO. 1
ULIC PUMP,
IPS SCAVENGE BLOWER
IPS SCAVENGE DUCT
INTEGRAL ANNULAR
OIL COOLER/BLOWER
TAIL ROTOR GEARBOX
(BEVEL GEARS)
ACCESSORY GEARBOX NO. 2
GENERATOR, HYDRAULIC PUMP
ENGINE COMPARTMENT
COOLING EJECTOR
794 SHP ADVANCED TECHNOLOGY ENGINE
INTEGRAL IPS/SCAVENGE BLOWER
FRONT DRIVE, 30,000 RPM OUTPUT SPEED
MAIN TRANSMISSION
(SPIRAL BEVEL AND
PLANETARY GEARS)
31.7:1 REDUCTION
INTERMEDIATE GEARBOX
(BEVEL GEARS)
SECTION THROUGH ENGINE COMPARTMENT
ACCESSORY/TRANSMISSION
COMPARTMENT COOLING AIR
ENGINE EXHAUST GAS
ENGINE COMPARTMENT
COOLING AIR
IPS SCAVENGE FLOW
FUEL CELL
CAPACITY = 211 GAL
0
20
40
60
80
100
INCHES

was mounted an electrical generator and a hydraulic pump. In addition, on the baseline aircraft, a rotor brake was mounted on the forward AGB and the integral oil cooler/blower mounted on the aft gearbox.

Accessory loads of 25 shp were used in the investigation to provide electrical, hydraulic, and mechanical blower power.

Transmission Losses

The losses assumed in study performance calculations for each of the transmissions and gearboxes are itemized below (percentage losses are based upon the total two-engine power output which is input to the aircraft drive system):

Engine Transmission	1.00 percent
Main Transmission	
Spiral Bevel Input	0.60
Spiral Bevel Tail Rotor (2)	0.08
Main Rotor Planetary	0.66
AGB Meshes	0.04
Intermediate Transmission	0.10
Tail Rotor Transmission	0.10
Accessory Gearbox	0.20
Total	2.78 percent

PROPULSION SYSTEM

The utility aircraft are powered by two advanced-technology turboshaft engines which offer the alternative of front or rear drive, and are capable of operating in a horizontal or vertical attitude at a 30,000-rpm output shaft speed. The selected engine has an integral inlet particle separator scavenged by an engine-mounted blower, and an integral oil system, including tank and fuel-oil cooler. At sea level/ 59°F and intermediate rated power (IRP), this engine produces 807 shp at the optimum output shaft speed and 794 shp at the design output shaft speed, 30,000 rpm. The engine installation provides sufficient cooling air induced by an exhaust-powered ejector to meet engine heat rejection rates and compartment temperature requirements. The induced airflow reduces the temperature of nacelle equipment and structure to the extent that surface temperatures and adequate ventilation prevent compartment fires which may result from fuel leakage.

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Engine Configuration and Weight

The advanced-technology engine for this application incorporates a high compressor pressure ratio to provide low specific fuel consumption (SFC) characteristics and a high turbine-inlet temperature to provide a specific horsepower of 165 shp/pound/second (output shaft horsepower per pound/second of engine airflow).

The engine installation drawing pictured in Figure 12 illustrates the configuration details, including the integral particle separator (IPS) scavenge blower and the integral oil system. The IPS blower system was assumed to weigh 10 percent of the total engine weight, 5 percent each for the IPS and for the blower. The weight of the baseline engine (including the IPS system) is 215 pounds.

The engine's integral oil system includes the tank and the fuel-oil cooler. Calculations indicated that the fuel-oil cooler provided adequate capacity to absorb the heat rejected to the engine oil. However, the SFC of an advanced-technology engine could prove too low to provide a sufficient reservoir for the heat rejection. In this event an air-oil cooler using particle separator scavenge airflow offers a suitable alternative heat sink. For either design, the total engine oil cooling system is integral with the engine.

The small advanced-technology engine has a relatively high compressor pressure ratio and gas generator speed, both of which impact engine starting requirements. The starter must accelerate the engine to a correspondingly higher starter cutout speed, and the compressor characteristics result in a high drag torque throughout the starting regime. These seemingly difficult starting requirements were the subject of some investigation to ensure that they would not have a major impact on the aircraft design. It was decided to incorporate an electrical starting system for the engine, and preliminary studies were conducted of battery voltage-current capability, degradation in capability at low ambient temperatures, starting system resistance, and the match with typical electrical starter characteristics. The results of these preliminary studies indicated sufficient electrical starting capability at standard ambient temperatures, but only marginal capability at lower temperatures, due to increasing engine drag torque and diminished battery capability. However, conversations with engine manufacturers relative to engine starting brought out the fact that the small advanced-technology gas generators on tests have exhibited lower starting power requirements than the predicted curves would indicate. This encourages the use of battery starting systems even for starts at lower ambient temperatures.

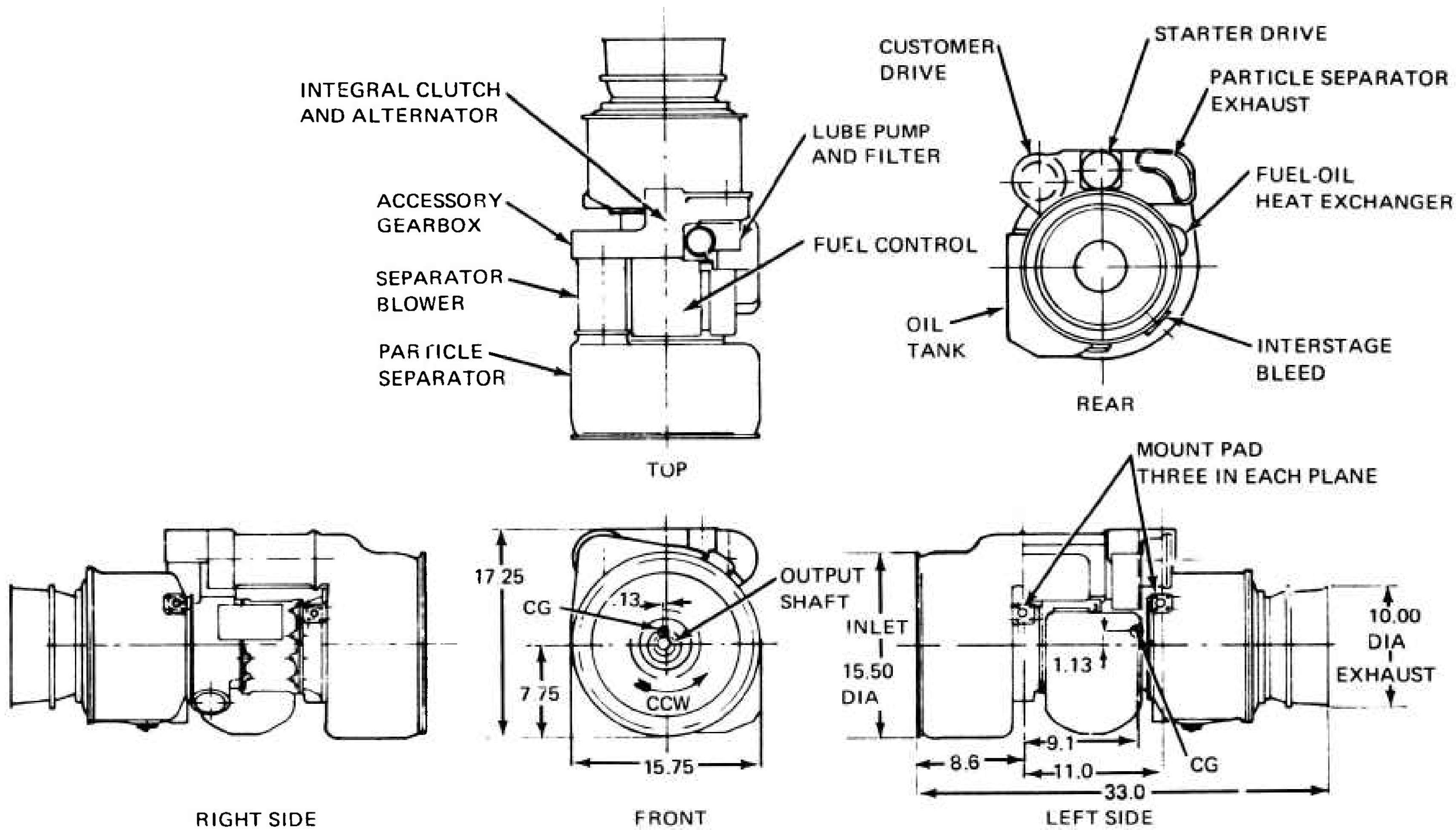

Figure 12. Three-View Installation Drawing of Advanced-Technology Engine.

Another concept which has merit for electrical starting systems is the use of two batteries in series to provide the initial high-voltage requirement, with a switching mechanism to switch to one of the batteries when the gas generator accelerates beyond the initial low speed-high drag torque regime of operation.

Engine customer bleed is available for aircraft cockpit and cabin heating requirements. Because of the small size of the engine, the percentage of bleed air permitted is small. But the bleed-air port is at the compressor exit, and the high pressure ratio and correspondingly high temperature result in reduced bleed flows to meet the aircraft heating requirements.

Engine Performance

Performance data were generated for the advanced-technology engines with no inlet particle separator or blower system. To simulate performance data of the engine with an integral IPS, typical inlet pressure loss and blower power corrections were applied (as illustrated in Figure 13). The resulting engine performance is pictured in Figure 14. Performance of the engine with no IPS system and performance with an integral IPS/blower are compared at 100 percent output shaft speed, 30,000 rpm.

Performance parameters for the engine operating at intermediate rated power (IRP) are listed in Table 5. Two configurations of the engine are considered, one with integral IPS and blower as configured for the baseline aircraft, and one with only the IPS and no blower as used in some of the advanced propulsion system concepts.

TABLE 5. ADVANCED-TECHNOLOGY ENGINE PERFORMANCE AT INTERMEDIATE POWER

	IPS/Blower		IPS/No Blower	
	S.L./59°F	4000 Ft/95°F	S.L./59°F	4000 Ft/95°F
Shaft Horsepower	794.	581.	799.	585.
SFC, lb/hr/shp	.489	.508	.485	.505
Output Shaft Speed, RPM	30,000	30,000	30,000	30,000
Engine Airflow, lb/sec	5.00	3.96	5.00	3.96
Exhaust Gas Temperature, °F		1100.		1100.

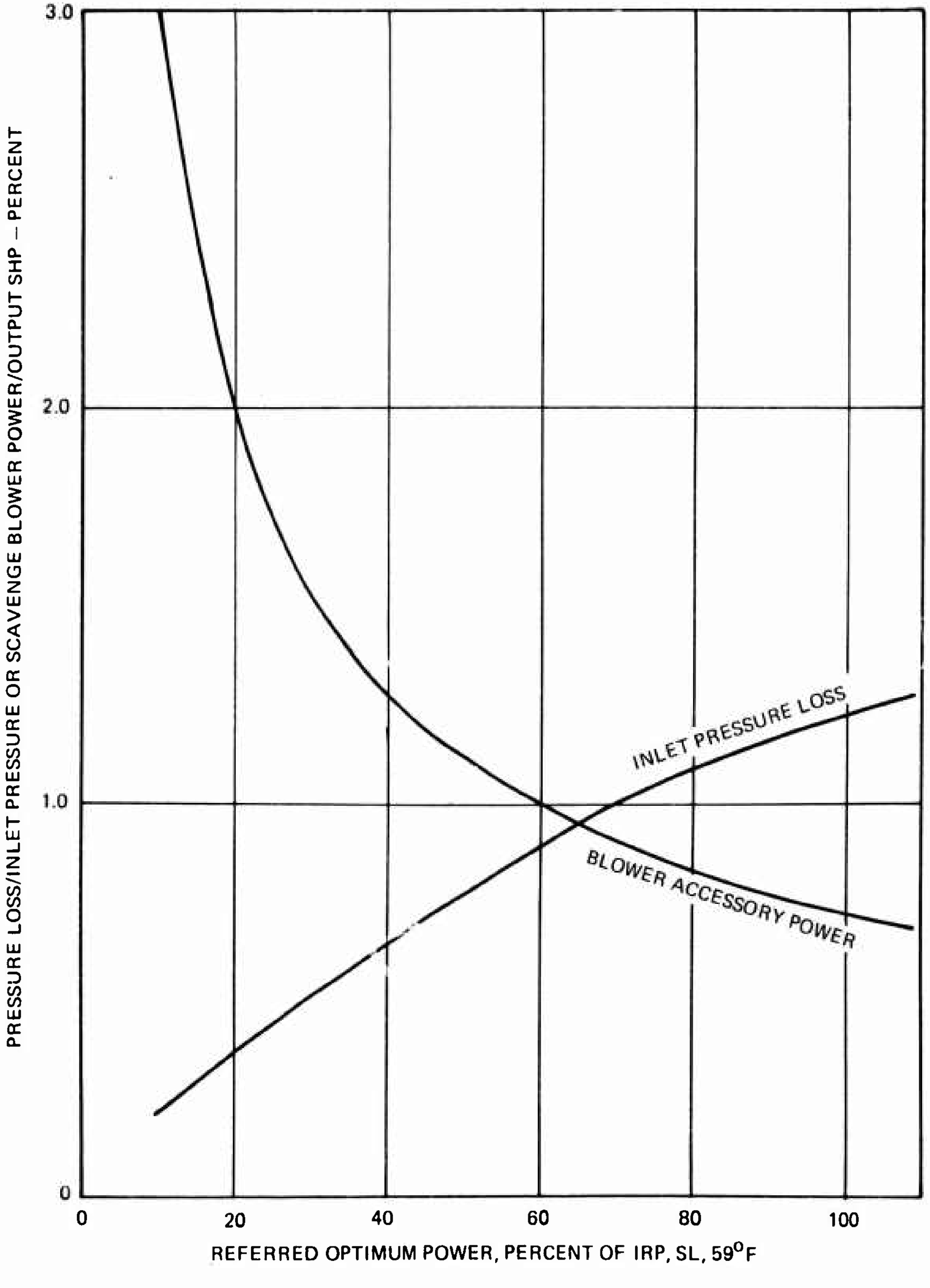

Figure 13. Inlet Particle Separator Pressure Loss and Scavenge Blower Accessory Power.

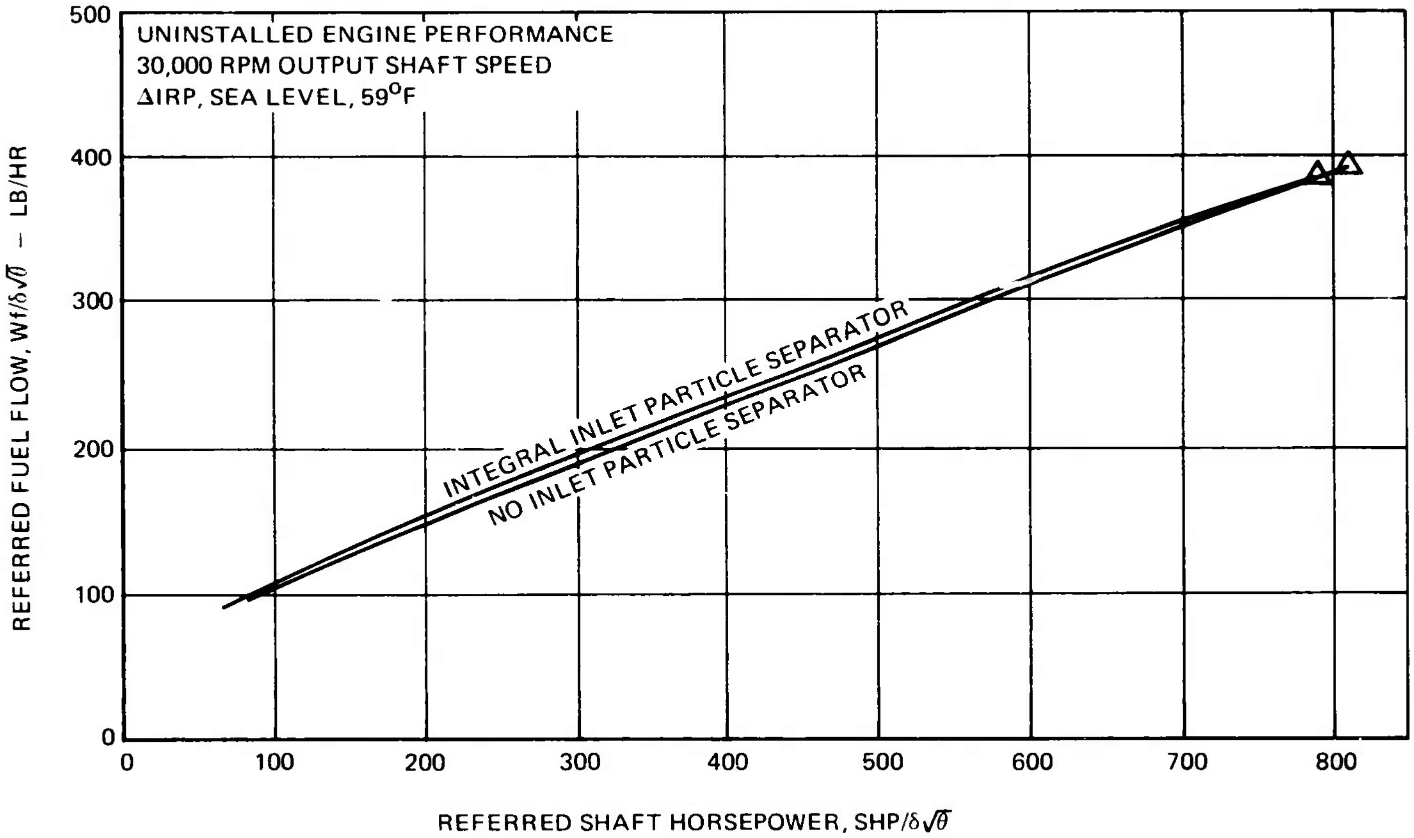

Figure 14. Advanced-Technology Engine Performance Data.

Engine Installation

The engine installation is configured to provide sufficient compartment cooling to (1) maintain engine surfaces, engine-mounted components, and airframe-mounted components below specified temperature limits; (2) to maintain airframe structure, particularly bonded materials and aluminum, below long-life temperature limits; and (3) to limit outer-skin temperatures consistent with IR suppression considerations. The installation is designed to meet appropriate military specifications and standards, including the following (Reference 2):

- Accessibility and maintainability (Paragraph 3.2.4.2)
- Nonflammable materials in engine compartment (3.11.2)
- Installation compatibility and mounts (3.11.3)
- Firewall thickness and flame resistance (3.11.4)
- Nacelle internal clearance and venting (3.11.5)
- Nacelle drainage (3.11.7)
- Engine intake location and design (3.12.5.2.2)
- Engine exhaust design and outboard cant (3.12.6)
- Compartment cooling requirements, hot day (3.12.7)

and from Reference 3:

- Limiting zone temperatures and air temperature limits (Paragraph 3.19).

Thermal Ignition

The compartment cooling concept used in the study design is adapted from the YUH-61A UTTAS and is the same as that employed in Boeing's CH-46 helicopter, as well as the prototype design

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(2) GENERAL SPECIFICATION FOR DESIGN AND CONSTRUCTION OF AIRCRAFT WEAPON SYSTEMS. VOLUME II - ROTARY WING AIRCRAFT, SD-24K, Vol. II, Department of the Navy, Naval Air Systems Command, Washington, D.C., 6 December 1971.

(3) MILITARY SPECIFICATION, ENGINES, AIRCRAFT, TURBOPROP, GENERAL SPECIFICATION for, MIL-E-8593(ASG), Department of the Air Force and Navy Bureau of Aeronautics, Washington, D.C., 3 September 1954.

of the XCH-62A--an ejector-pumped compartment cooling air system. It was assumed that the engine bay comprised a single continuous annular compartment surrounding the engine, with appropriately located cooling air inlets. Ambient air introduced through these openings provides cooling flow through the compartment. The cooling flow is induced by the ejector pump at the engine exhaust tailpipe or by ejector action powered by the integrated blower system.

The engine installation incorporated a longitudinal firewall to separate the engine compartment from the airframe structure, but not a lateral firewall, which would interfere with engine-exhaust ejector compartment cooling. This nacelle design was based on the premise that adequate compartment ventilation and reduced surface temperatures within the engine compartment will prevent the occurrence of thermal ignition as a result of fuel spillage. Substantiating data is provided in Reference 4, which documents an FAA test program to determine nacelle environmental conditions which produce thermal ignition, using a JT3D-1 turbofan installation. Test data confirmed that fuel leaks from an unpressurized fuel system and sufficient changes of compartment air per minute permit surface temperatures up to 1100°F without thermal ignition.

The FAA test program investigated fuel leakage occurring in the nacelle combustor-turbine section and in the compressor-accessory section (the production JT3D-1 nacelle has a fire seal between the two sections). Simulated fuel leakage conditions in each section were divided into a number of test categories depending upon nacelle configuration, powerplant operating condition, and simulated pressurized or unpressurized fuel system. In the nacelle configurations with controlled cooling flow, thermal ignition occurred only in the minimum compartment airflow range. This effect of nacelle ventilation on thermal ignition is illustrated in Figure 15. Sufficient ventilation prevents ignition up to 950°F engine exhaust gas temperature or higher, depending upon type of fuel (Type A, kerosene,or Type B, JP-4). If ventilation is sufficient to prevent ignition at 950°F exhaust gas temperature, this corresponds to engine surface temperatures within the nacelle of nearly 1100°F. Compartment ventilation rate in the helicopter is very high, and is sufficient to reduce surface temperatures below the thermal ignition point. Based upon the facts noted above, an exception to the military specification was

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(4) AN INVESTIGATION OF IN-FLIGHT FIRE PROTECTION WITH A TURBOFAN POWERPLANT INSTALLATION, Report No. NA-69-26, Department of Transportation, Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, New Jersey, April 1969, AD686 045.

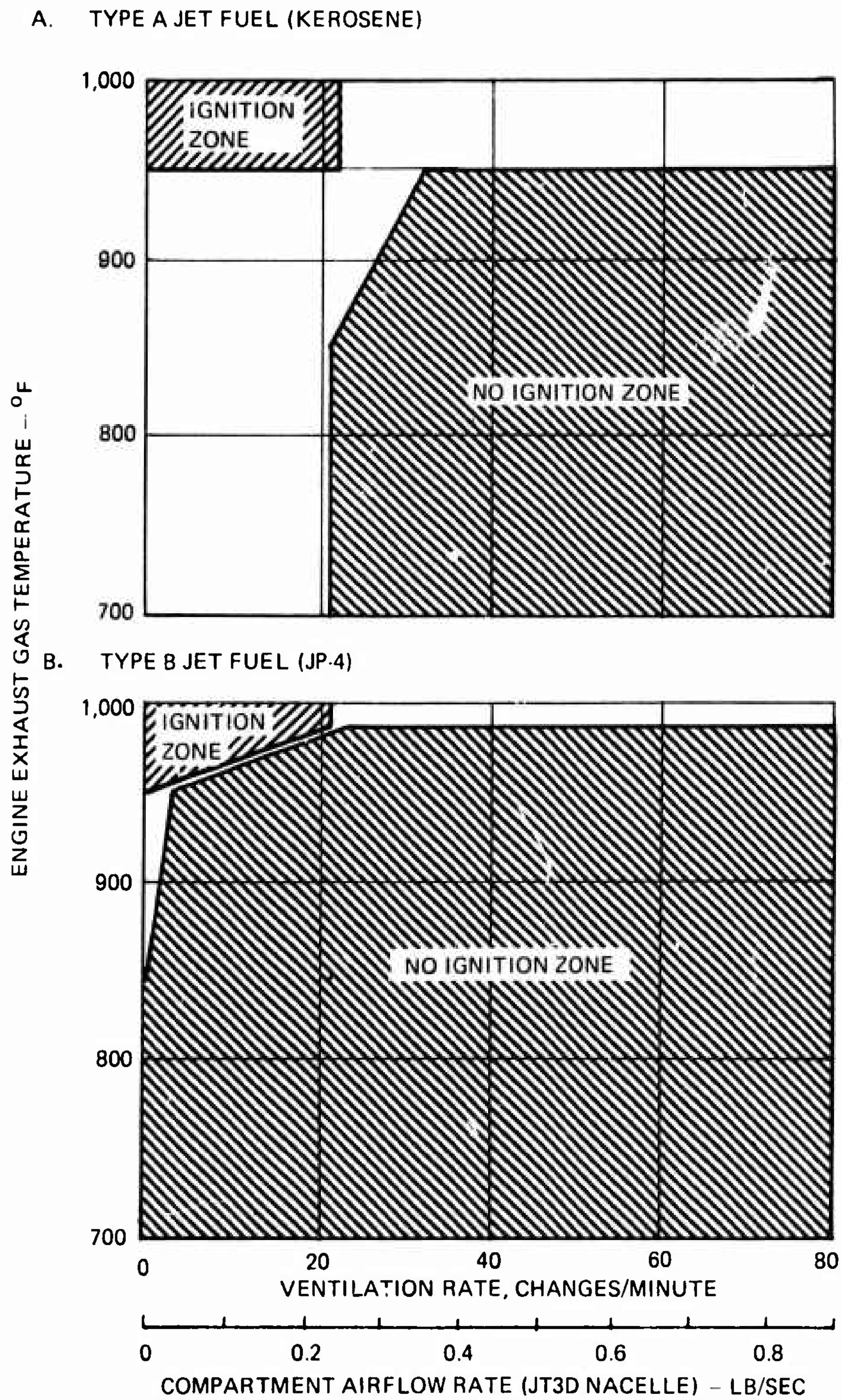


Figure 15. Engine Compartment Ventilation Required to Prevent Thermal Ignition of Fuel.

taken in the design of the baseline aircraft, relative to the use of fire shields to prevent leakage of combustible fluids from reaching hot parts.

Engine Compartment Cooling

An estimate of the compartment cooling flow induced by the ejector pump at the engine exhaust is based upon measured data obtained during tests of the YUH-61A engine nacelle. The amount of cooling flow was determined by scaling in direct proportion to the engine airflow, and resulted in an induced flow of 1.23 lb/sec at IRP, 4000 feet, 95°F, ambient conditions.

An analysis of compartment temperatures and insulation requirements was performed based upon predicted cooling airflow, engine skin temperatures and heat rejection rates. Results of the analysis included engine skin temperature, cooling air temperature, and the nacelle structure inner and outer surface temperatures as functions of axial position. Because of the relatively high engine skin temperatures typical of advanced-technology engines, the predominant mode of heat transfer from the engine was radiation. Component emissivities were estimated from known surface finish characteristics; view factors between component surfaces and hot nacelle and engine surfaces were computed by numerical integration; and radiant transfer was calculated between each engine skin segment and all nacelle segments within 10 inches axially. In calculating convection coefficients within the nacelle, the engine and cowl surfaces were treated as a series of flat plates, with the characteristic dimensions (length) assigned as input parameters. Typically, the governing equation for laminar flow was used, but in the case of an exceptionally high cooling flow rate, turbulent convection coefficients were utilized in the analysis. In the calculations the convection coefficient for the outer nacelle surfaces versus station was used with suitable adjustments for downwash and forward velocity effects. The analyses considered heat conduction from the engine, convection to the compartment cooling air, and radiation to and from the engine hot end and the nacelle inner surfaces.

To evaluate the most critical engine cooling requirements, compartment temperatures were calculated for engine operation at IRP, sea level, 130° - compartment airflow was 1.25 lb/sec at this condition. Results of the analysis are presented in Figure 16. It was determined that a 1.0-inch insulating blanket would be needed on the nacelle inner wall, and through selective use of insulating material in areas where engine peak skin temperatures occurred, external nacelle temperatures were limited to 200°F or less.

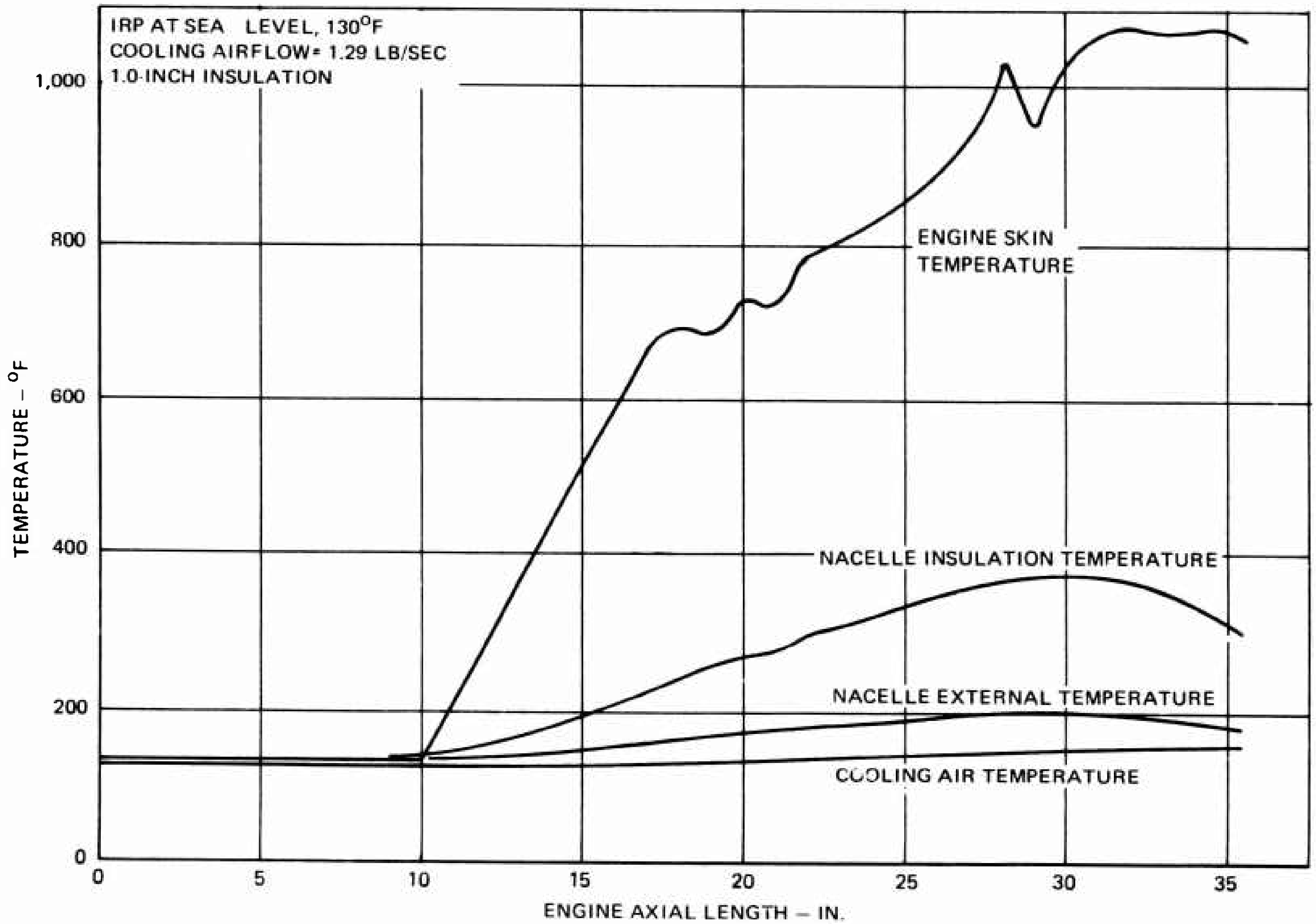


Figure 16. Engine Compartment Surface and Cooling Air Temperatures.

ADVANCED CONCEPT REQUIREMENTS

Airflows for the engine inlet and inlet separator scavenge, engine and drive train compartment cooling, transmission oil cooling, and engine hot metal and exhaust plume IR signature suppression were integrated in each of the six advanced propulsion system integration concepts. The integration of the various external airflows is illustrated in Figure 17, and the calculated flows and temperatures are tabulated in Appendix A.

Cooling Airflow Blower

A transmission-driven blower was required to provide the cooling airflow for the propulsion system integration concepts. The blower design point was 20 inches of water pressure rise to overcome the pressure losses encountered in ventilating the drive system compartment, passing through the oil cooler core, and flowing through the ducts to the IR suppressor, where a substantial total pressure head is desired to provide ejector-action plume dilution and hot metal suppressor surface cooling. The blower design point at 4000 feet, 95°F, was:

Pressure Rise = 20 in. water

Airflow = 17.8 lb/sec

Inlet Temperature = 100°F

Blower adiabatic efficiency was assumed to be 0.60, resulting in a temperature rise of 15°F. Blower power required was 90 shp. A mixed-flow impeller configuration was selected, rather than an axial-flow blower, because it provides greater structural integrity. The mixed-flow design also offers increased tolerance to small caliber gunfire. Backward leaning vanes were incorporated into the mixed-flow impeller to minimize exit swirl. Tip speed was 600 feet/second, which resulted in an exit swirl velocity of 150 feet/second at the tip diameter of 20 inches.

IR Suppression System

Required levels of engine hot metal IR suppression and exhaust plume dilution were established for the advanced propulsion system integration concepts. The maximum temperature of the suppressed exhaust plume was not to exceed 400°F at an engine exhaust gas temperature of 1100°F (IRP, 4000 feet, 95°F). This amount of plume dilution was required over the entire flight spectrum.

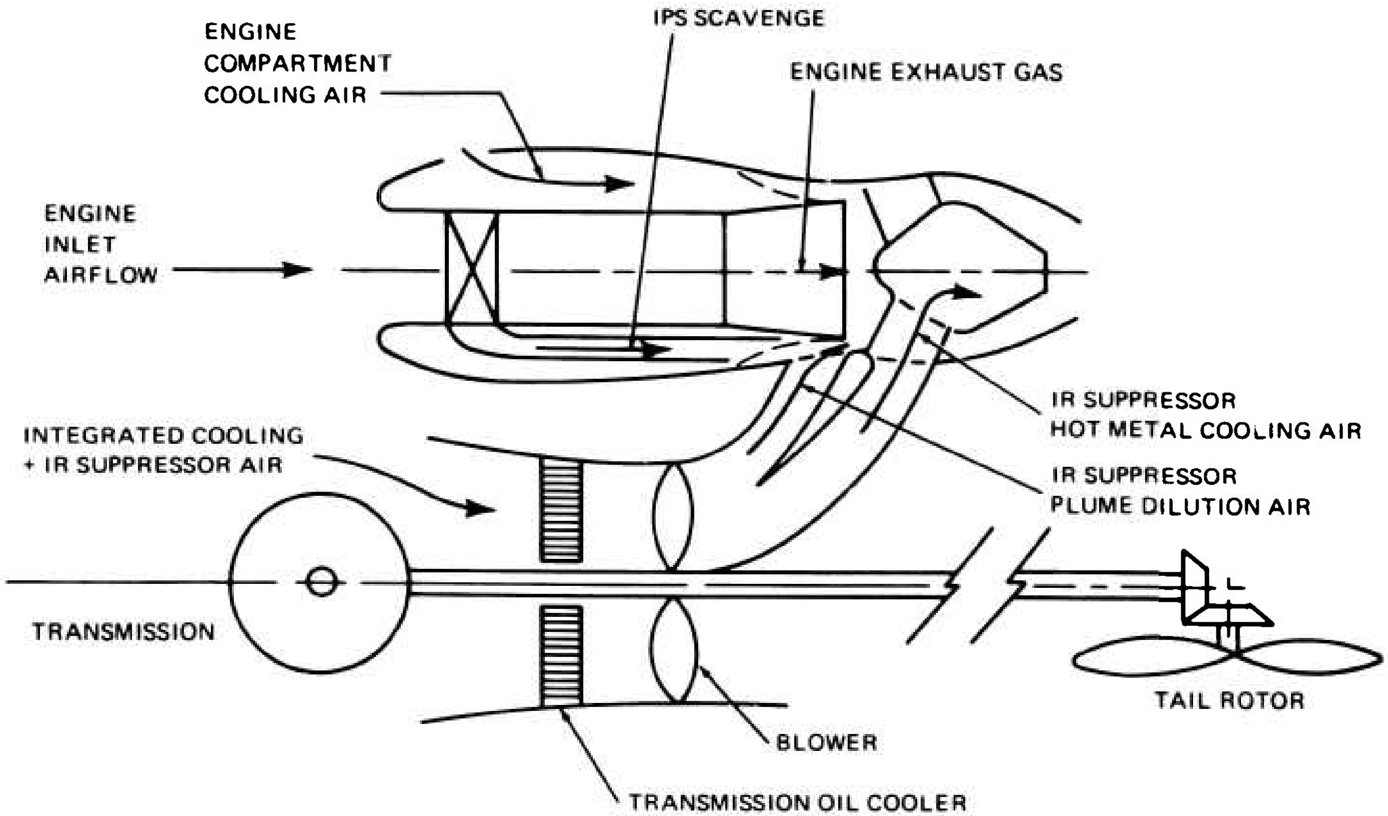


Figure 17. Schematic Drawing of Integrated Airflows.

The suppressor configurations also were required to provide shielding of the engine hot metal to prevent direct viewing. Correlation of the area of exposed hot metal suppressor surface and the corresponding allowable level of surface temperature is provided in Figure 18. The hot metal area-temperature relationship of Figure 18 results in an IR signature substantially less than that of the 400°F exhaust plume. Although the hot metal signature experiences very slight atmospheric attenuation, the plume signature attenuates very rapidly with distance from the source. However, if the aircraft were at a distance of 1.0 km or less from the IR missile launch point, the intensity of the plume signature would still be very significant in comparison to the hot metal signature, the two being of virtually equal importance.

The requirement for exhaust plume dilution dictated the amount of cooling air available for IR suppression and resulted in a large quantity of available air for hot metal cooling. Therefore, a design goal of 200°F metal surface temperature was established for the suppressor. The exposed hot metal surface area for the suppressed engine concepts was only slightly larger than 3.0 sq ft, considerably less than the limiting hot metal area from Figure 18 corresponding to 200°F. Consequently, the resulting hot metal signature of the advanced concepts was much lower than that defined by the metal temperature-area relationship of Figure 18.

Appendix A provides calculated values of significant parameters of IR suppressor performance for the advanced integration concepts. Only a fraction of the total blower-supplied cooling airflow is designated for hot metal cooling. However, this fraction of cooling air would provide 0.25 lb air/second/square foot of surface area and a predicted effectiveness of 0.85, which is sufficient to ensure the metal surface temperature is less than 200°F.

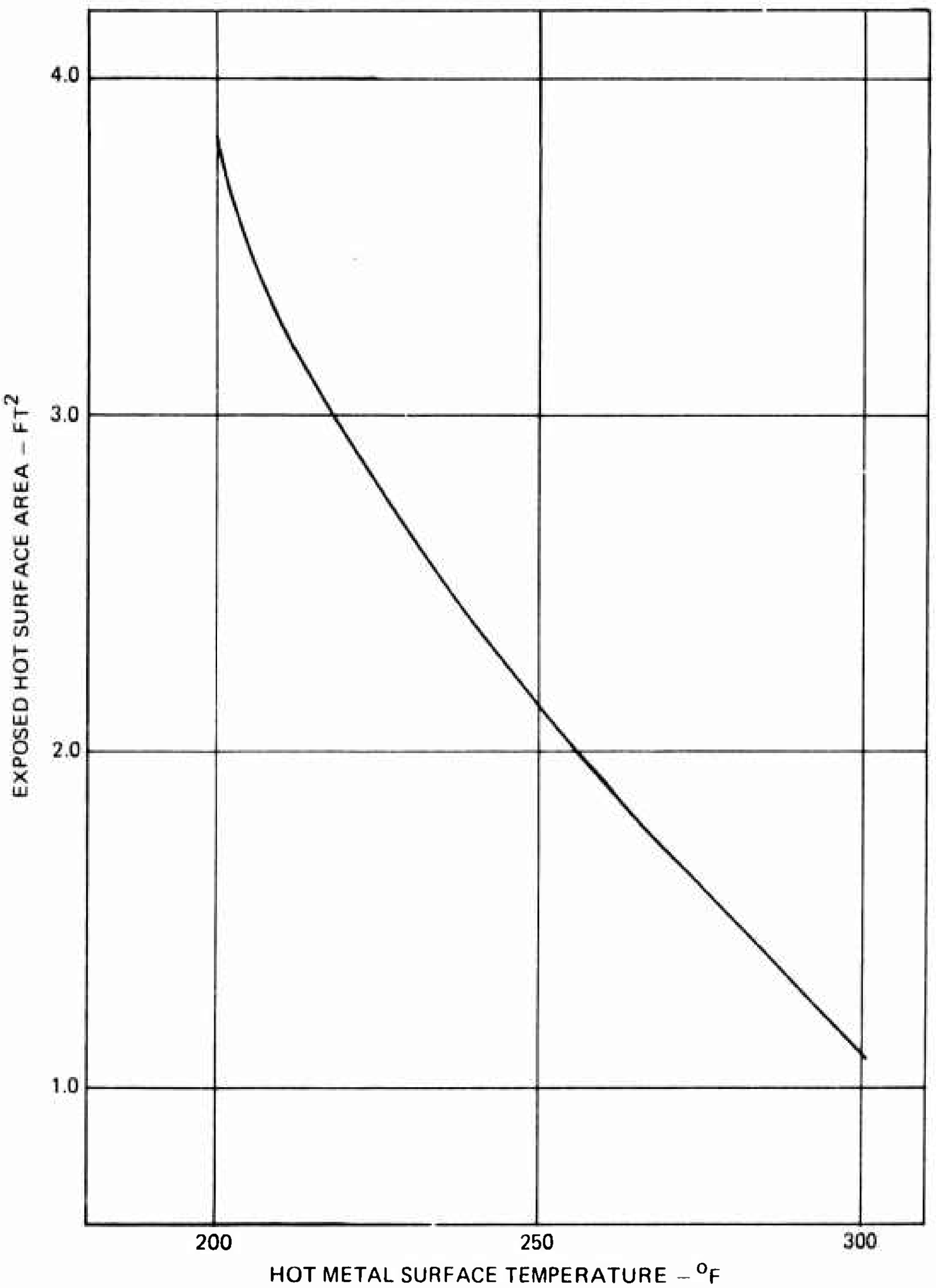


Figure 18. Hot Metal IR Suppression Criteria.

CONFIGURATION DESCRIPTION

BASELINE AIRCRAFT DESIGN VARIANTS

Six innovative engine/transmission/airframe integrated design concepts were developed which meet the total airflow requirements for a utility transport helicopter. These requirements include engine compartment cooling, drive train and transmission oil cooling, engine exhaust plume and hot metal IR signature suppression, and engine inlet particle separator scavenging. The baseline and six unique concepts studied are listed below and schematically pictured in Figure 19:

1. Front-angle drive, horizontal, parallel, pod-mounted engines with tail rotor (Baseline Concept a).

2. Front-angle drive, horizontal, parallel, pod-mounted engines with transmission-driven blower integral with tail rotor drive (Concept b).

3. Front-angle drive, horizontal, splayed, pod-mounted engines with fan-in-fuselage (Concept c).

4. Front-direct drive, vertical, buried engines with transmission-driven blower, with tail rotor (Concept d).

5. Rear-angle drive, horizontal, parallel, pod-mounted engines with transmission-driven ducted fan, integral with tail rotor drive (Concept e).

6. Rear-direct drive, horizontal, splayed, sponson-mounted engines with blower integral with tail rotor drive (Concept f).

7. Rear-direct drive, vertical, buried engines with transmission-driven blower integral with tail rotor drive (Concept g).

The variant configurations were derived from the baseline design and retained the same main rotor and engines, and all configurations possessed the same design gross weight and payload. Except for the fan-in-fuselage configuration, all used the baseline aircraft's tail rotor. The ground rules used in the development of the baseline aircraft were applied to the conceptual variants with the exception of the vertical climb performance which was permitted to vary.

At the time the drag analysis was performed for these configurations, boundary layer suction was considered as a means to prevent flow separation and reduce drag. A review indicated that the mechanism would add weight and complexity, reducing or eliminating the small benefits available through boundary control. Careful fairing of the fuselage, pylon, hub and nacelle interfaces could produce equal or greater benefits.

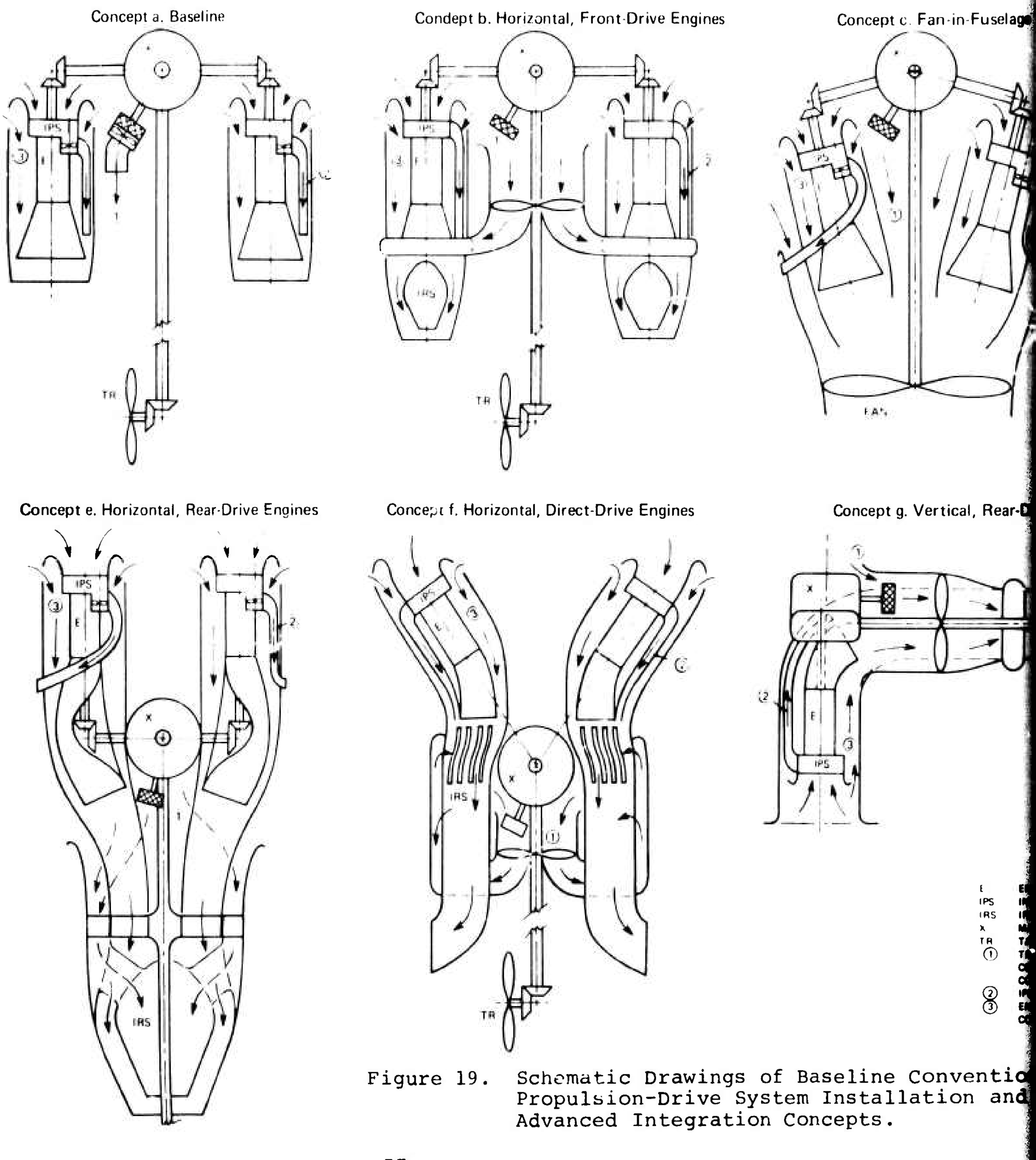
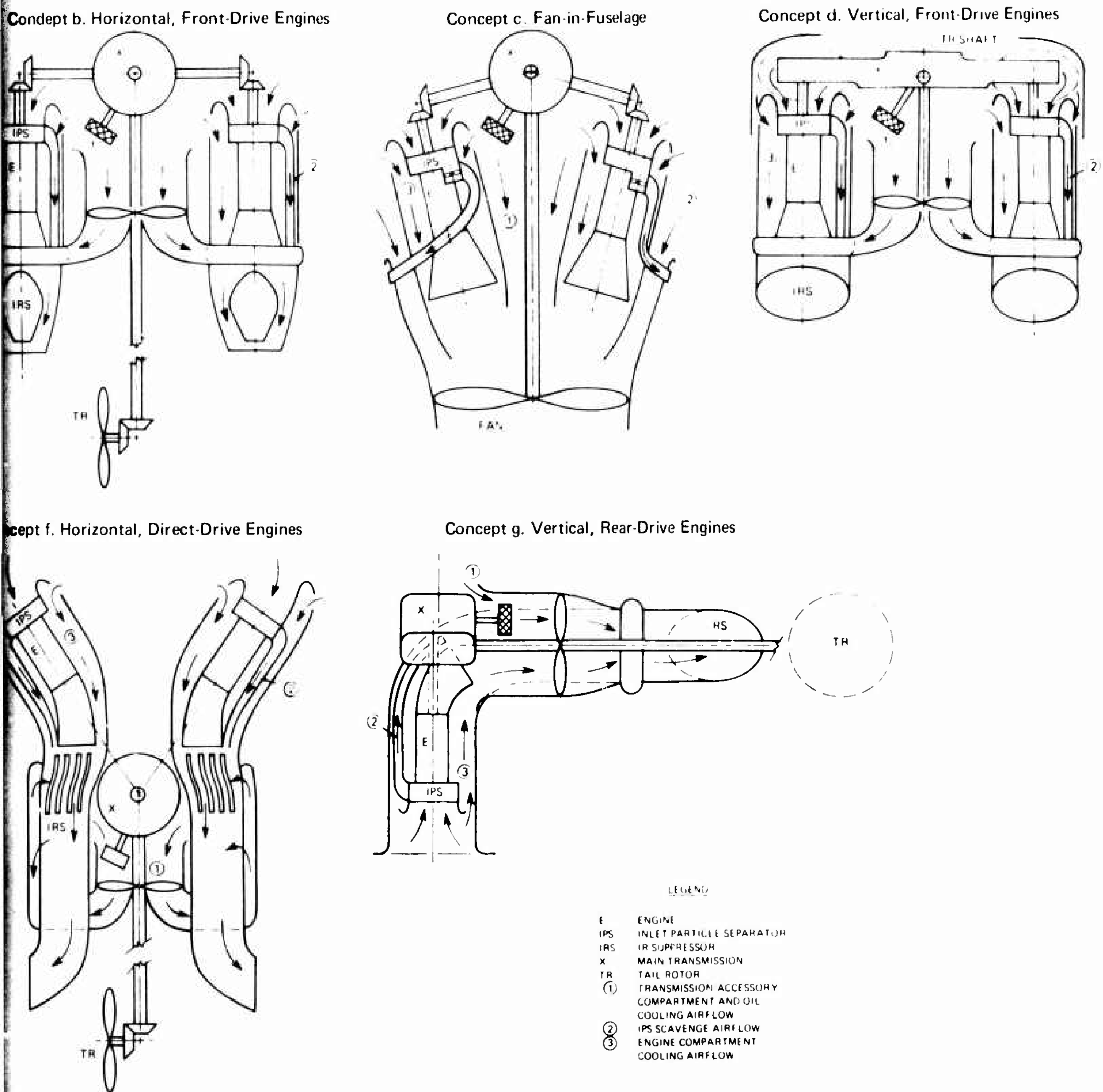


Figure 19. Schematic Drawings of Baseline Conventio Propulsion-Drive System Installation and Advanced Integration Concepts.



ure 19. Schematic Drawings of Baseline Conventional Propulsion-Drive System Installation and Six Advanced Integration Concepts.

For these reasons, boundary layer suction was not recommended for application in the advanced aircraft configurations.

Of the initial six propulsion integration concepts, three were selected for preliminary design, based upon comparative analyses and evaluation of overall system performance, system complexity, aircraft system weight, system design, technical risk, and control requirements.

PROPULSION SYSTEM ARRANGEMENTS

Conceptual designs were produced for the baseline utility helicopter propulsion-drive system and six variant concepts with integrated airflow arrangements. A brief description of each of the arrangements follows.

Baseline Aircraft

The baseline aircraft (Figure 11) incorporates front-drive engines, pod-mounted horizontally and parallel to each other, with the engine transmission mounted on the engine front frame and a right-angle, bevel-gear drive into the main rotor transmission. The direct mounting of the engine transmission to the engine permits a reasonable installation for the high-speed (30,000 rpm) engine output shaft. The single-stage bevel mesh in this transmission permits the "sprag" clutch to be located on a low-speed shaft. The conventional main transmission consists of a spiral-bevel collector gear and a one-stage planetary gear.

The speed reduction in the engine transmission permits the use of only two reduction stages in the main rotor transmission, allowing a low profile main rotor transmission which permits C-130 and C-141 loading without hub removal.

The tail rotor drive shaft and pads for a hydraulic pump, an alternator, and a separate blower integral with the oil cooler are provided on the aft accessory gearbox at the rear of the transmission. The integral oil cooler/blower system handles oil cooling requirements for the main transmission, both the aft and forward accessory gearboxes and both engine nose gearboxes with air exhausted overboard. The forward accessory gearbox provides redundant hydraulic and electrical power in addition to a rotor brake. Cooling of the accessories and drive system compartment is by free-air convection.

An engine-exhaust powered ejector is used to induce engine compartment cooling airflow which dumps into the combined nacelle exhaust duct. Similarly, IPS blower exhaust is ducted to the rear of the engine compartment, where the contaminated air is sucked out by the ejector.

The antitorque tail rotor intermediate (angle) gearbox contains a simple spiral bevel mesh with splash lubrication and convection cooling. The tail rotor gearbox consists of a simple right angle spiral bevel arrangement.

A backup lubrication system without cooling is provided for the main transmission, which includes a pump, screen, reservoir, passages, jets and pressure sensing system.

No IR suppression system is incorporated in the baseline configuration.

Horizontal, Parallel, Front-Drive Engine Arrangement

This configuration offers the same basic engine/transmission/airframe system arrangement as the baseline aircraft, but incorporates total airflow and power management for subsystem cooling and IR suppression. A low pressure ratio mixed-flow blower, driven off the main rotor transmission and concentric with the tail rotor drive shaft, provides cooling air for the drive system, as well as for IR suppressor hot-metal cooling and exhaust plume dilution. This integrated propulsion-drive system installation is pictured in Figure 20.

The blower air is collected in a large scroll with individual ducts to each IR suppressor unit, which deliver cooling air to an annular plenum surrounding the suppressor and exhaust system where it is divided for hot metal cooling and straight exhaust plume dilution. The blower scroll collector offers the possibility of an on-off dump valve (cockpit operated) to unload the blower when IR suppression is not required.

The mixed flow blower occupies the volume previously used for the aft accessory gearbox; therefore, for this concept both the accessory gearboxes are separately mounted, side by side, forward of the main rotor transmission with armor plate between to reduce vulnerability. A common inlet duct located on top and at the aft section of the cabin at the aircraft's centerline provides cooling air for the AGB's, main transmission and the integrated centrifugal blower. The free-stream air cools the AGB's, the main transmission, and the annular oil cooler before it enters the blower inlet.

Internal to the IR suppressor, the blower cooling air flows through a "daisy-mixer" arrangement to augment the engine exhaust, and provides an effective ejector system. Sufficient ejector action is achieved for scavenging the engine inlet particle separator and for inducing compartment cooling air. This arrangement obviates the requirement for an engine-mounted IPS blower, thereby reducing the engine accessory power requirements. The proposed IPS scavenge concept parallels similar design concepts based upon ejector-induced

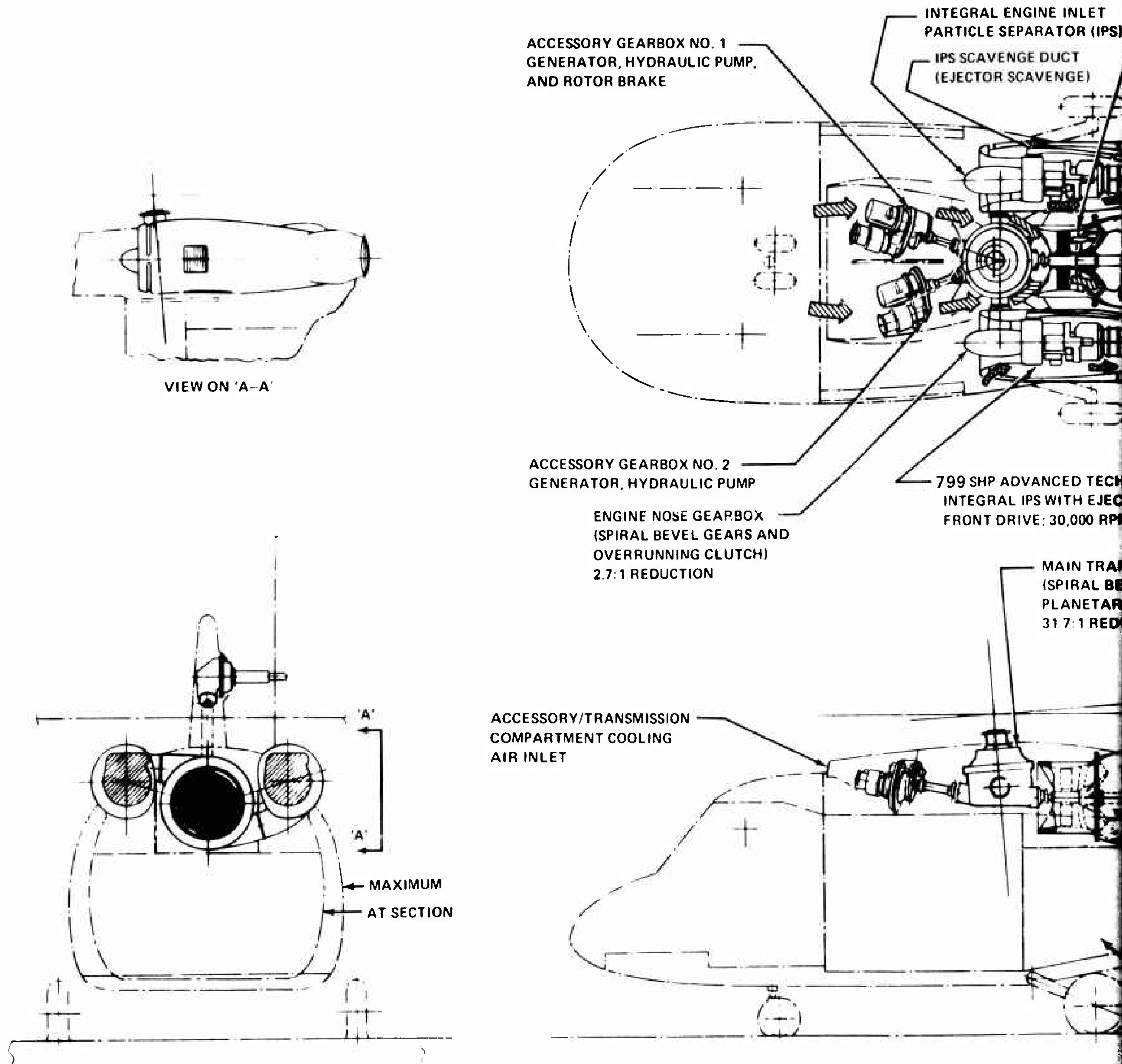
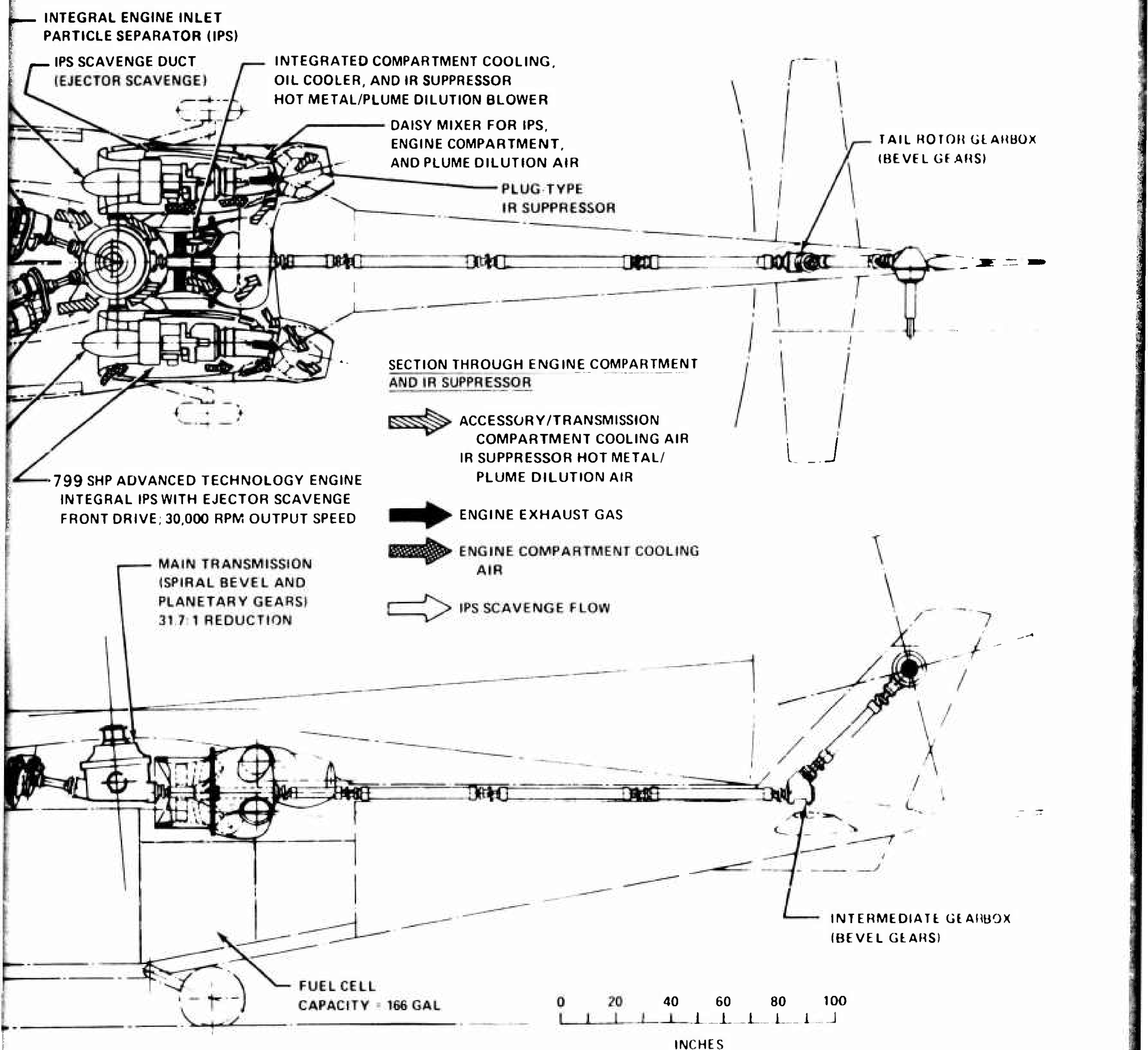


Figure 20. Concept b, Integrated Propulsion-Drive System Installation (Horizontal, Front-Drive Engines).


INTEGRAL ENGINE INLET PARTICLE SEPARATOR (IPS)
IPS SCAVENGE DUCT (EJECTOR SCAVENGE)
INTEGRATED COMPARTMENT COOLING, OIL COOLER, AND IR SUPPRESSOR HOT METAL/PLUME DILUTION BLOWER
DAISY MIXER FOR IPS, ENGINE COMPARTMENT, AND PLUME DILUTION AIR
PLUG TYPE IR SUPPRESSOR
TAIL ROTOR GEARBOX (BEVEL GEARS)
SECTION THROUGH ENGINE COMPARTMENT AND IR SUPPRESSOR
ACCESSORY/TRANSMISSION COMPARTMENT COOLING AIR
IR SUPPRESSOR HOT METAL/ PLUME DILUTION AIR
ENGINE EXHAUST GAS
ENGINE COMPARTMENT COOLING AIR
IPS SCAVENGE FLOW
799 SHP ADVANCED TECHNOLOGY ENGINE INTEGRAL IPS WITH EJECTOR SCAVENGE FRONT DRIVE; 30,000 RPM OUTPUT SPEED
MAIN TRANSMISSION (SPIRAL BEVEL AND PLANETARY GEARS) 31.7:1 REDUCTION
INTERMEDIATE GEARBOX (BEVEL GEARS)
FUEL CELL CAPACITY = 166 GAL
0 20 40 60 80 100
INCHES

scavenge flows. Presented in Figure 21 is rig test data for such a concept, which substantiates the capability of an ejector scavenge system and indicates that it is a viable design concept.

Boundary layer control could be exercised for this configuration by locating a BLC slot or perforated wall on aircraft surfaces having severe flow separation or base drag, and matching flow areas to provide controlled flows satisfying the blower airflow requirement with a minimum of duct losses. However, no BLC configuration was considered, and no drag benefits which could be ascribed to boundary layer suction were incorporated.

Fan-In-Fuselage Concept

The fan-in-fuselage concept pictured in Figure 22 departs from the conventional antitorque tail rotor and incorporates a large mechanically driven, fuselage-mounted, variable pitch, ducted fan with adjustable louvers in the tail for antitorque control. The fan-in-fuselage antitorque technique lends itself uniquely to an integrated propulsive system providing for an efficient air management system. Within the size constraints of the aircraft, the largest possible fan diameter results in the lowest power penalty, which offsets the increase in duct size and weight.

The front-drive engines are at an angle to the main transmission (i.e., splayed), but otherwise the main rotor drive system is similar to previous concepts. The engine IPS air is ducted overboard and not into the fan, to prevent the contaminated air from reducing the reliability and life of the antitorque unit. An integral engine-mounted IPS blower is therefore required with the associated weight and power penalties.

The forward accessory gearbox (AGB) with the integral rotor brake is mounted similarly to the baseline. The aft AGB is integrated with the ducted fan offset drive system.

Initial mixing of the engine compartment cooling air with engine exhaust reduces the temperature of mixed flow impinging locally on fan structure to 875°F. At the inlet face of the fan, accessory compartment ventilation airflow and airflow introduced through the scoop inlets dilutes the fan flow to a temperature level of 157°F, which does not compromise the variable pitch fan size or design. The total mixed flow requirement for antitorque control is 130 lb/sec, far greater than the amount required for engine exhaust plume dilution. Downstream of the fan, the temperature of the flow in the duct is 160°F. Despite the 160°F temperature, the hot metal IR signature of the exhaust louver cascade is

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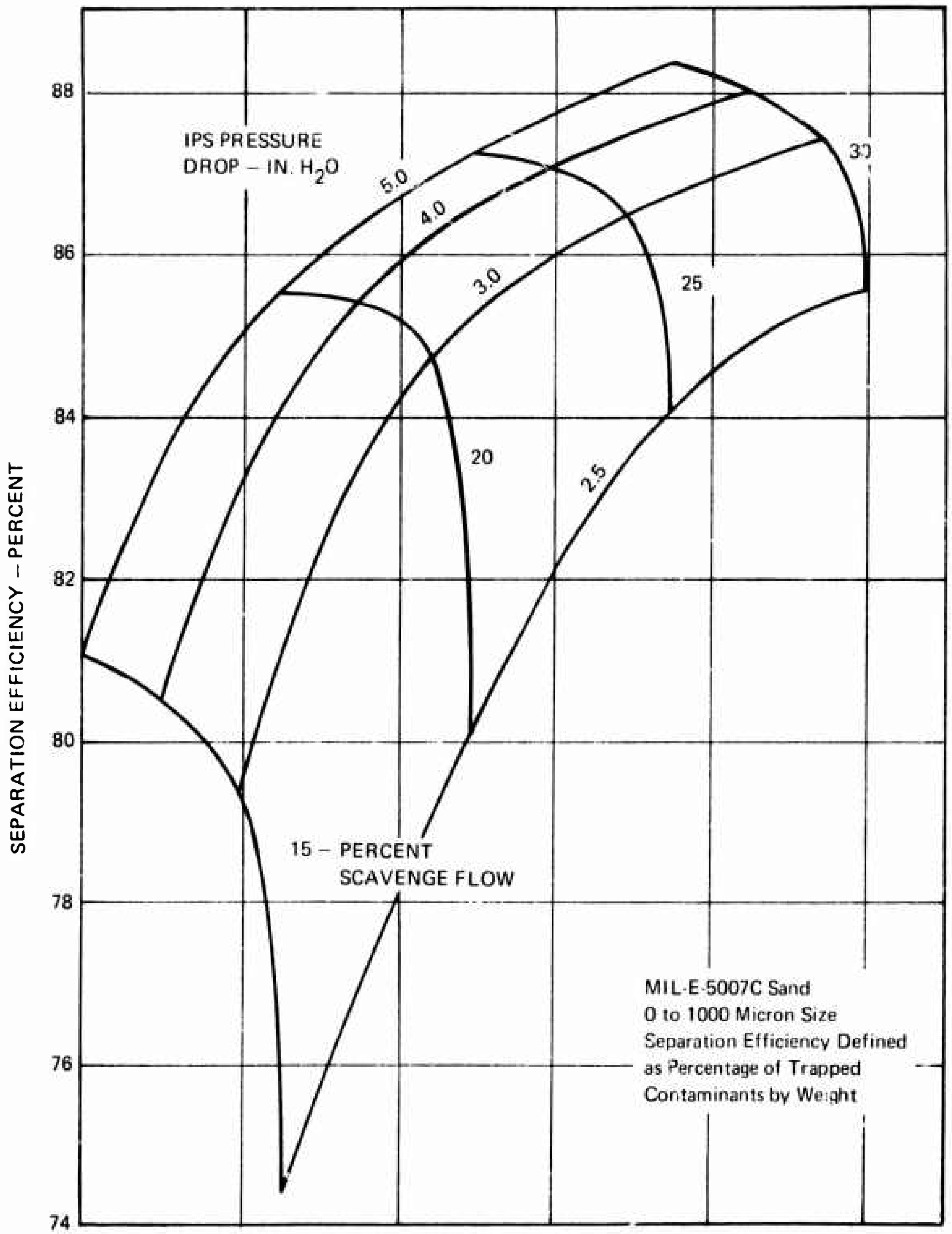


Figure 21. Test Rig Performance of Low Pressure Loss Particle Separator Scavenge System.

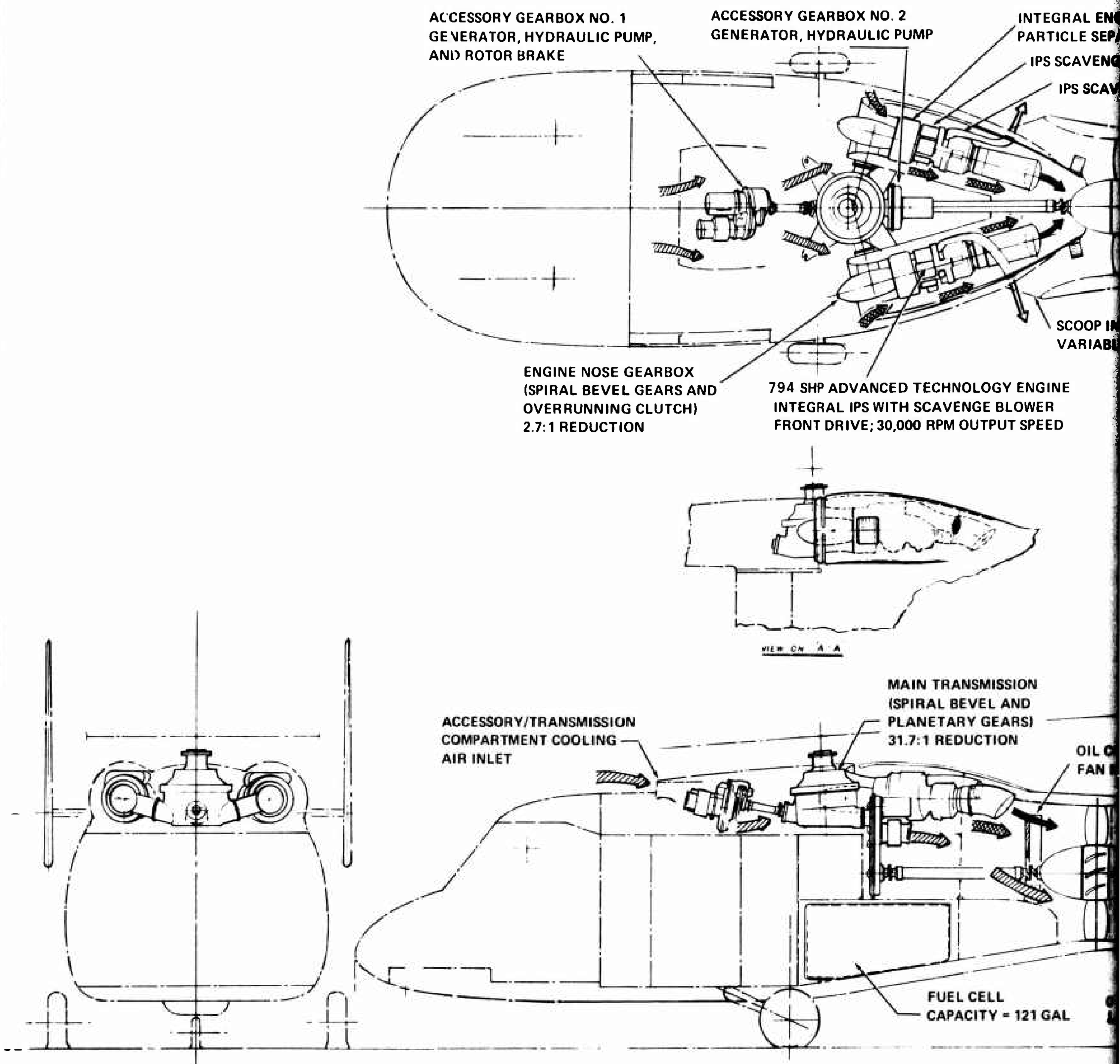
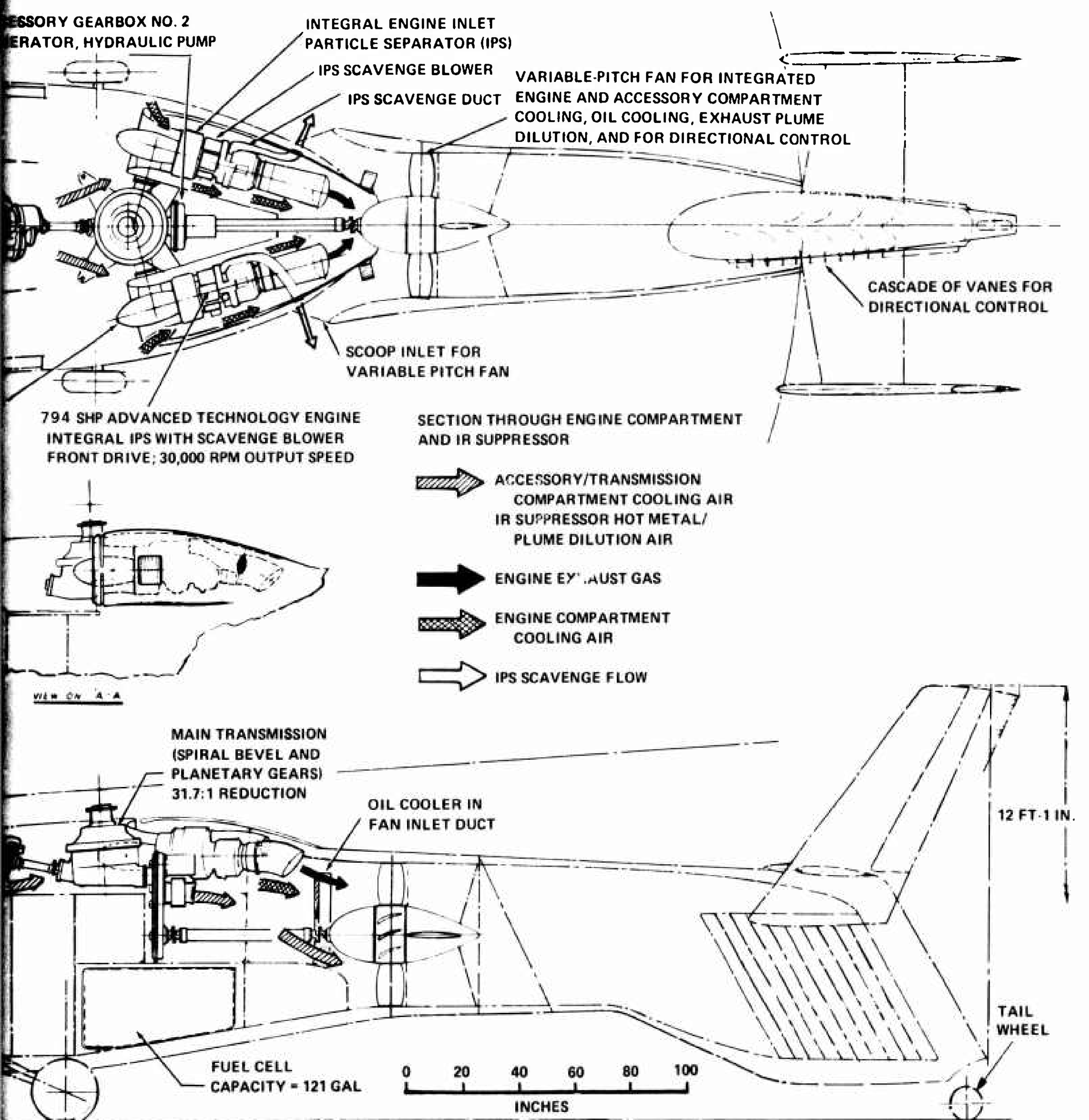


Figure 22. Concept c, Integrated Propulsion-Drive System Installation (Fan-in-Fuselage).



ESSORY GEARBOX NO. 2
ERATOR, HYDRAULIC PUMP
INTEGRAL ENGINE INLET PARTICLE SEPARATOR (IPS)
IPS SCAVENGE BLOWER
IPS SCAVENGE DUCT
VARIABLE-PITCH FAN FOR INTEGRATED ENGINE AND ACCESSORY COMPARTMENT COOLING, OIL COOLING, EXHAUST PLUME DILUTION, AND FOR DIRECTIONAL CONTROL
CASCADE OF VANES FOR DIRECTIONAL CONTROL
SCOOP INLET FOR VARIABLE PITCH FAN
794 SHP ADVANCED TECHNOLOGY ENGINE
INTEGRAL IPS WITH SCAVENGE BLOWER
FRONT DRIVE; 30,000 RPM OUTPUT SPEED
SECTION THROUGH ENGINE COMPARTMENT AND IR SUPPRESSOR
ACCESSORY/TRANSMISSION COMPARTMENT COOLING AIR
IR SUPPRESSOR HOT METAL/ PLUME DILUTION AIR
ENGINE EXHAUST GAS
ENGINE COMPARTMENT COOLING AIR
IPS SCAVENGE FLOW
MAIN TRANSMISSION (SPIRAL BEVEL AND PLANETARY GEARS) 31.7:1 REDUCTION
OIL COOLER IN FAN INLET DUCT
12 FT-1 IN.
TAIL WHEEL
FUEL CELL CAPACITY = 121 GAL
0
20
40
60
80
100
INCHES

System

significantly greater than the limit corresponding to Figure 18, due to its large area, but the much lower exhaust plume IR signature compensates for this.

To duct the fan flow to the antitorque louver device requires a relatively large tail boom, which increases aircraft weight. This increase in weight necessitates the use of the tail wheel as opposed to the nose wheel for the baseline aircraft.

A dual vertical tail arrangement provides aircraft directional forward flight stability for the fan configuration. The overall length of this concept is larger than the baseline aircraft with the forward fuselage length increased by 18 inches to achieve the desired balance.

Vertical, Front-Drive Engine Concept

The vertical, front-drive engine installation pictured in Figure 23 has a direct drive into the main rotor transmission. Aircraft width is extended to accommodate the twin engine remote locations, and the rear bulkhead of the passenger compartment is moved from underneath the main transmission to accommodate the vertical engine installation. The main landing gear is moved forward, and to accommodate the shift in center of gravity, the aircraft utilizes a tail wheel instead of a nose wheel.

To provide hot metal and plume dilution airflow, the blower is vertically mounted between the engines and driven mechanically and separately from the main transmission. The blower arrangement exhaust is ducted to an ejector arrangement in the suppressor to provide compartment cooling air and IPS scavenging, and IR suppression. The vertical engine installation lends itself to a vane IR suppressor concept instead of a plug arrangement. Vanes at the exhaust duct exit, cooled by blower airflow, provide shielding of the hot metal. This vertical engine and IR blower arrangement have the same accessory gearbox arrangements as the baseline aircraft.

A conventional tail rotor drive system is employed driving through the aft accessory gearbox. Like the baseline, a ram inlet duct forward of the rotor hub and on top of the cabin provides cooling air for the necessary gearboxes, the main transmission, and for the IR blower, which also houses the integral annular oil cooler.

Separate ram inlets provide airflow into plenum chambers upstream of each engine installation. Bellmouth inlets oriented

vertically are attached to each engine with bulkheads between the engine face and the plenum. Adequate clearance is provided to permit sufficient air to enter for engine compartment cooling. The separate ram inlets for engine air are located outboard and at the cabin height to provide an integrated system with the aircraft surfaces.

The overall dimensions of this concept are increased over the baseline aircraft with the forward part of the fuselage extended forward to accommodate the vertical engine installation underneath the main transmission.

<u>Horizontal, Parallel, Rear-Drive Engine Concept</u>

This rear-drive engine installation uses a variation of the conventional rear-drive engine configuration tail pipe to bypass exhaust gas around the engine transmission and by the main transmission. As shown in Figure 24, engines are mounted outboard, horizontal, and parallel above the cabin and forward of the main transmission. The engine inlet incorporates a short straight-in annular inlet duct to provide maximum pressure recovery. The inlet location reduces the danger of hot exhaust reingestion, as well as minimizes the danger from foreign object damage (FOD).

The engine IPS and engine-mounted blower discharge inlet contaminants through a separate duct and overboard.

A dual-element blower of fixed geometry, concentric with the tail rotor drive shaft, serves several purposes:

- The inner element induces engine exhaust air and compartment cooling air through ducts leading from the engine exhaust.

- The outer element induces cooling air from a separate free-stream ram inlet located along the top of the cabin, through the accessory compartment, and through the transmission oil cooler.

- The outer element charges the hot metal cooling panels of the plug-type IR suppressor and provides cooling air to mix with the exhaust gas through the trailing edge of the suppressor struts. Directional vanes at the exit of the suppressor could be required to prevent hot mixed flow impingement on the tail boom.

Placement of the dual element blower requires an aft extension of the rotor pylon, and in combination with IR suppressor plug and fuel tanks necessitates the relocation of the aft AGB. Both accessory gearboxes are located forward of the main transmission with armor plate between them to reduce

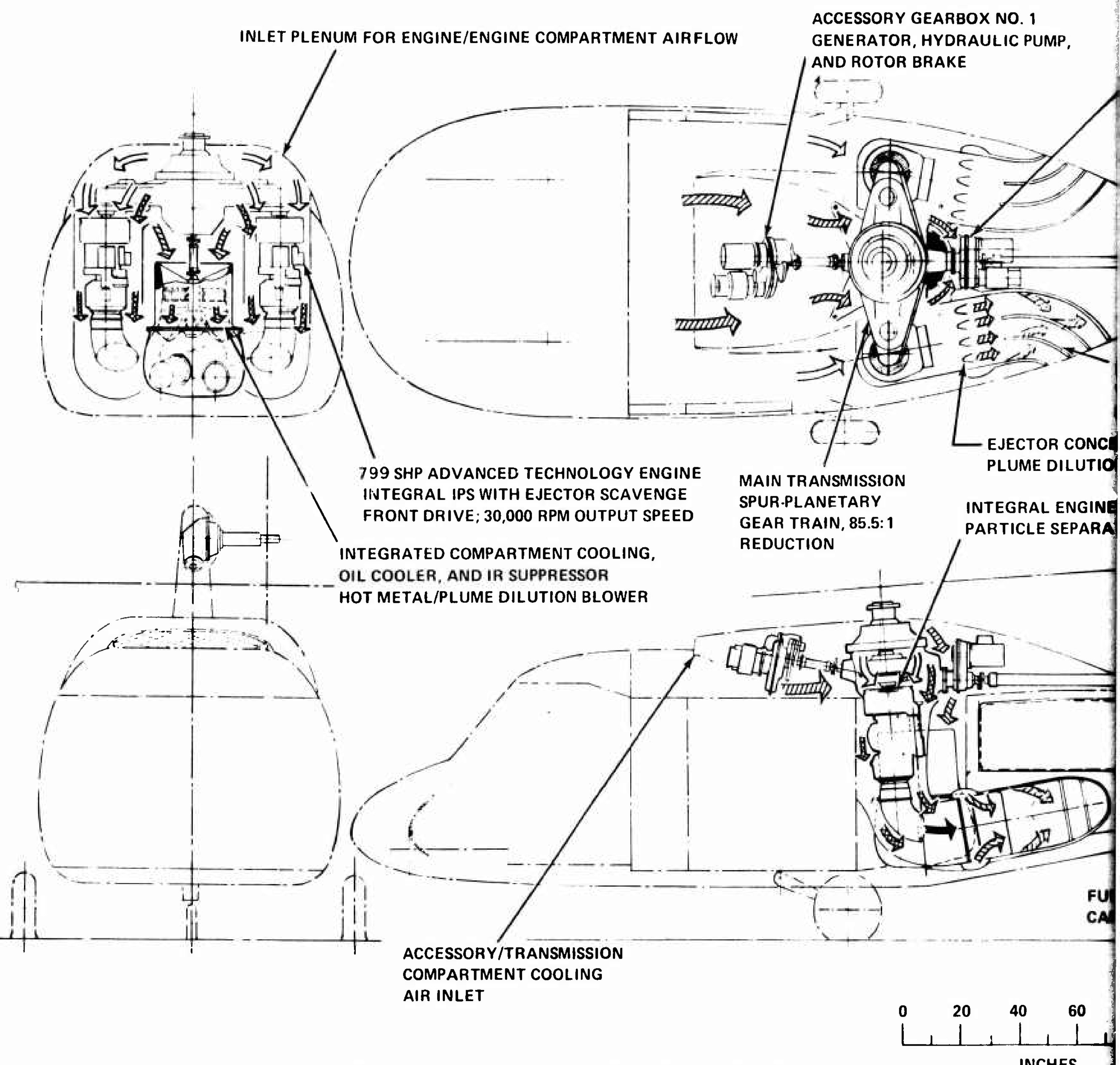
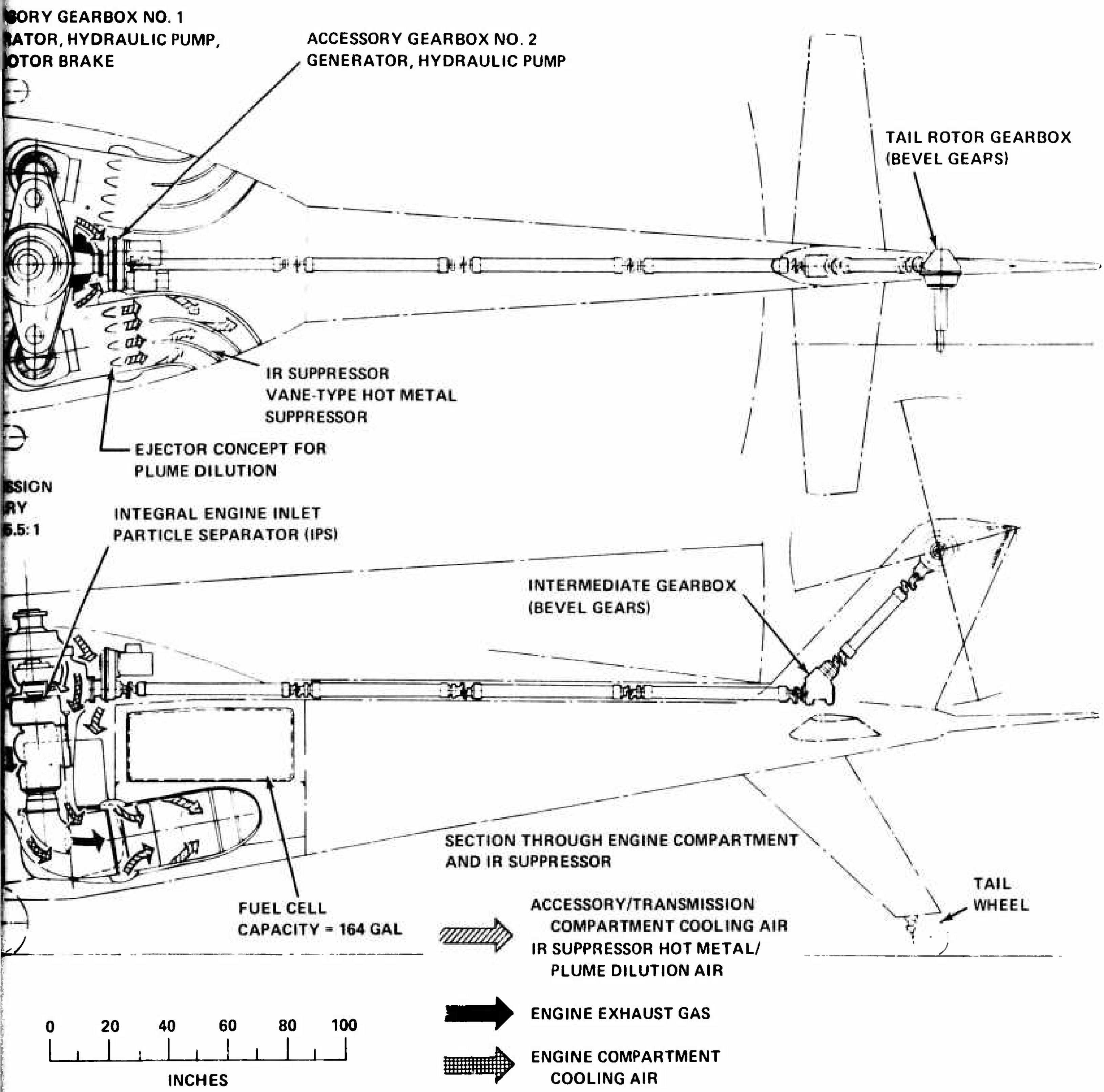


Figure 23. Concept d, Integrated Propulsion-Drive System Installation (Vertical, Front-Drive Engines).



ORY GEARBOX NO. 1
ATOR, HYDRAULIC PUMP,
OTOR BRAKE
ACCESSORY GEARBOX NO. 2
GENERATOR, HYDRAULIC PUMP
TAIL ROTOR GEARBOX
(BEVEL GEARS)
IR SUPPRESSOR
VANE-TYPE HOT METAL
SUPPRESSOR
EJECTOR CONCEPT FOR
PLUME DILUTION
SSION
RY
5.5:1
INTEGRAL ENGINE INLET
PARTICLE SEPARATOR (IPS)
INTERMEDIATE GEARBOX
(BEVEL GEARS)
SECTION THROUGH ENGINE COMPARTMENT
AND IR SUPPRESSOR
TAIL
WHEEL
FUEL CELL
CAPACITY = 164 GAL
ACCESSORY/TRANSMISSION
COMPARTMENT COOLING AIR
IR SUPPRESSOR HOT METAL/
PLUME DILUTION AIR
ENGINE EXHAUST GAS
ENGINE COMPARTMENT
COOLING AIR
ENGINE INLET AIRFLOW
0
20
40
60
80
100
INCHES

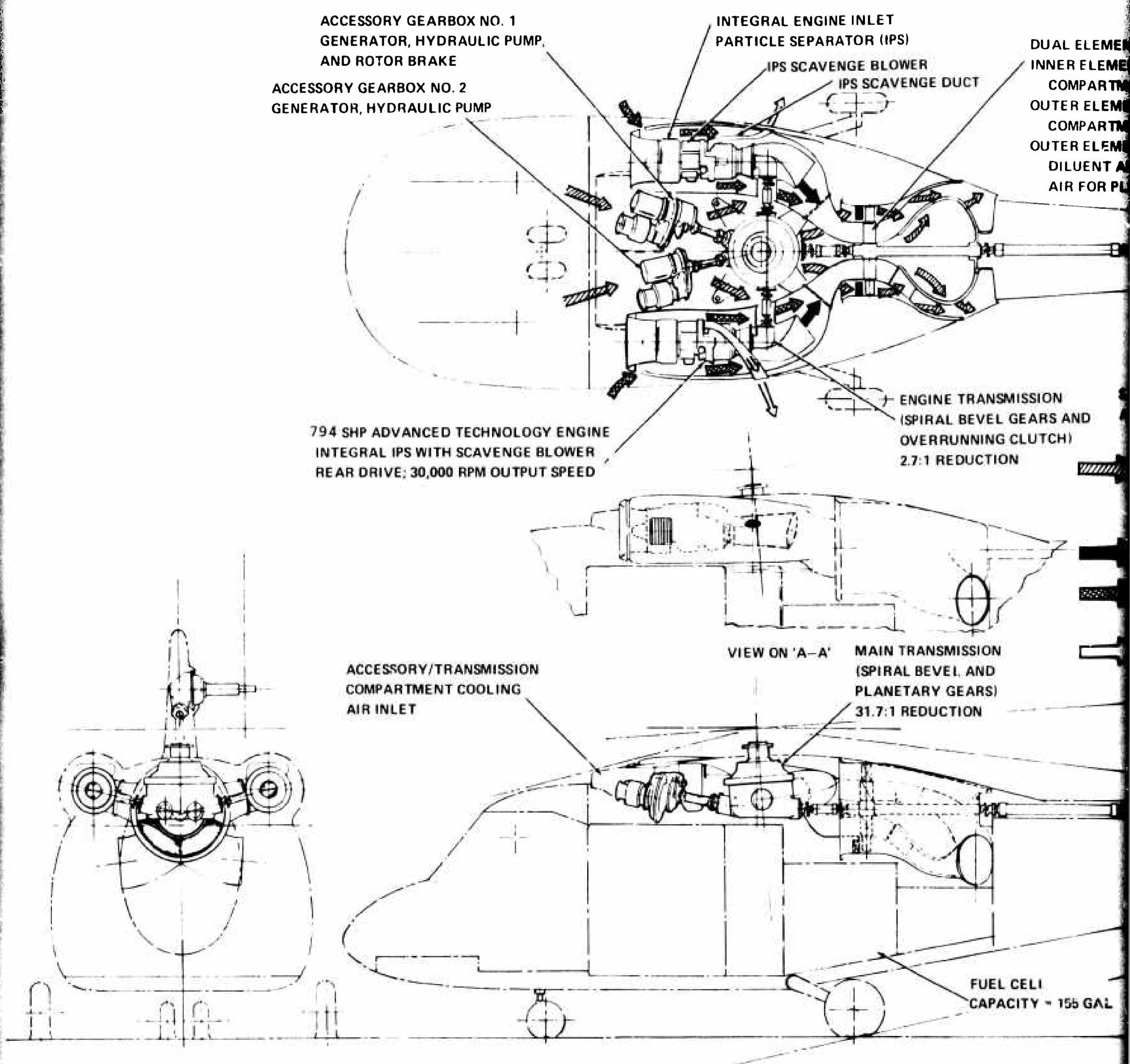


Figure 24. Concept e, Integrated Propulsion-Drive System Installation (Horizontal, Rear-Drive Engines).

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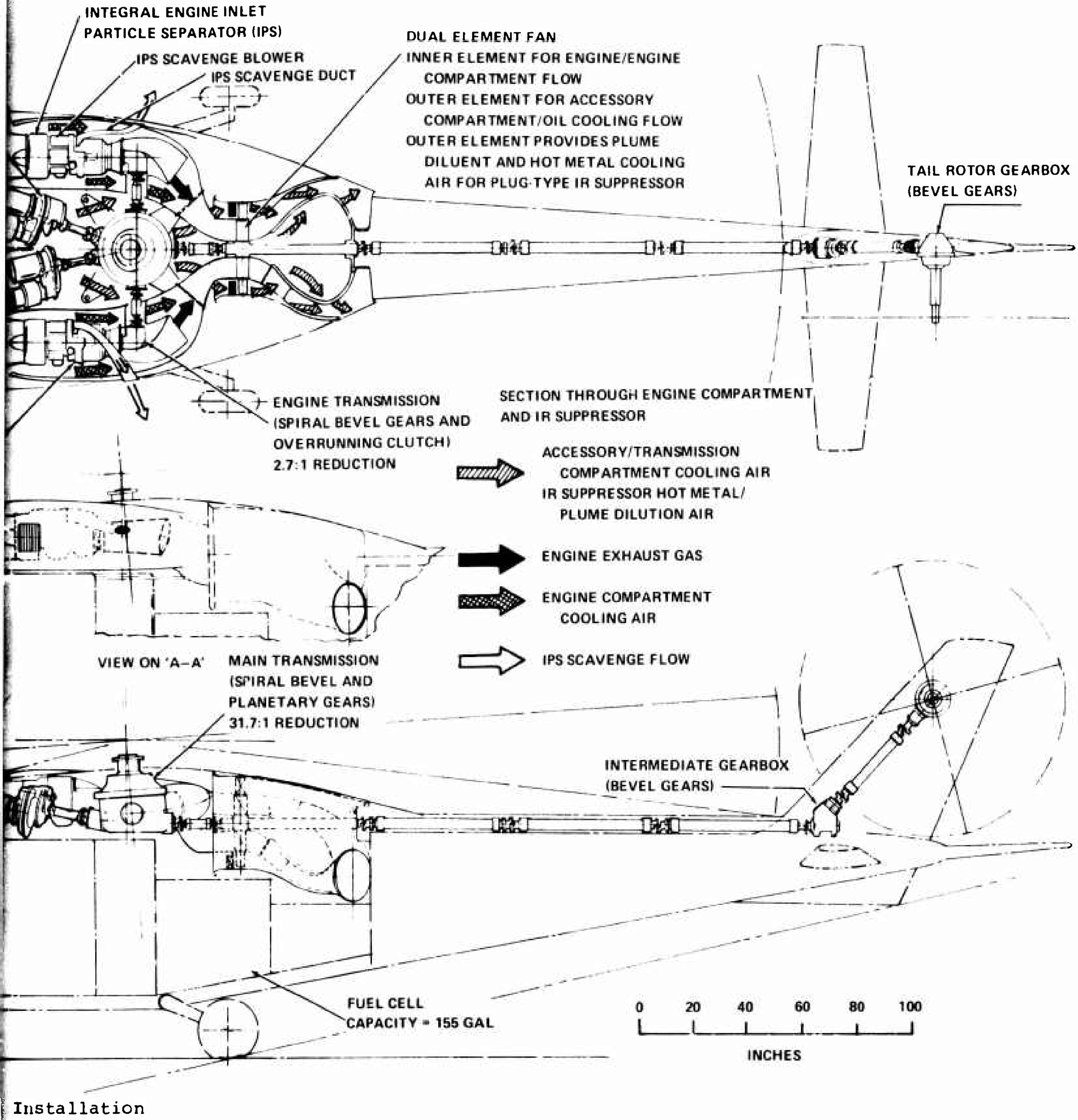

Installation

vulnerability.

The baseline aircraft type main landing gear tail rotor, drive system and nose wheel are used with this configuration. The overall dimensions for this concept remain the same as for the baseline aircraft.

Horizontal, Direct Rear-Drive Engine Concept

An aircraft-supplied inlet particle separator is integrated with the sponson inlet in this concept. The concept is pictured in Figure 25 with an aircraft-mounted IPS and the engine separator and blower removed. The splayed engine arrangement enables the engines to drive directly into the main transmission without an angle gearbox or engine transmission. In addition, this arrangement provides a clean inlet with a moderate turn angle that results in good inlet performance.

In this configuration a large transmission-mounted, mixed-flow blower is located directly aft of the main transmission and integrated with the tail rotor drive. The location of this large blower for IR suppression cooling air necessitates the relocation of the aft accessory gearbox. Both accessory gearboxes are therefore located forward of the main transmission with armor plate between them to reduce vulnerability.

A ram inlet located above the cabin forward of the main transmission ducts free-stream air for cooling of the accessory gearboxes and main transmission. Part of the cooling air is used by the blower to power an ejector, which induces engine compartment airflow and IPS scavenge air. In addition, the blower air is used to charge the plenum chamber surrounding the engine exhaust. The air is discharged through slots to suppress the main engine exhaust plume temperatures to meet the IR suppression requirements. The plume dilution air also bathes the walls of the "jumbo-slot" duct inside and outside, providing film cooling to keep the metal temperatures below 200°F. Hiding turning vanes are located at the exhaust discharge to prevent line-of-sight radiation from the engine hot metal.

The conventional antitorque tail rotor system and landing gear (nose and main gear) are incorporated in this configuration. The overall dimensions of the concept remain the same as for the baseline aircraft.

To minimize the IR suppressor blower size and power requirements of the horizontal, direct rear-drive engine concept, a jumbo-slot cooling technique using rotor downwash to film cool the duct wall and provide additional plume dilution is utilized in an alternate design of this concept shown in

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Figure 25.

This alternate scheme uses a cooled plug at the engine exhaust to shield hot metal from view, followed by a mixing duct which uses air from the smaller integrated IR blower for plume dilution. The remainder of plume dilution is achieved by the rotor downwash airflow mixing with the main exhaust flow by ejector action through the "jumbo slots."

The overall dimensions of the alternate configuration remain the same as for the baseline aircraft.

Vertical, Rear-Drive Engine Concept

Figure 26 is a 3-view drawing of the vertical rear-drive engine concept. In this concept, the transmission has been reconfigured to move the engine's centerline aft, so the rear bulkhead of the passenger cabin can remain in the same position as the baseline aircraft. Engine airflow enters through a screen port in the side of the aircraft into a plenum volume. Although the engine is mounted vertically with its inlet facing downward, the inlet port is located near the top of the fuselage to minimize exhaust gas reingestion and FOD. The free-stream air is ducted into a large plenum extending along the side of the fuselage, to the bottom, and in the front of the engine. The engine has a bellmouth inlet facing downward.

The engine installation uses a variation of the rear-drive tail-pipe configuration to bypass the main engine exhaust flow around the direct rear drive into the main transmission. Spur gears are used in the main rotor transmission with a built-in integral overrunning clutch arrangement. Main ring gear size was increased to accommodate the high engine drive input speed.

The IPS and IPS blower are integral with the engine, and the scavenge air is ducted into the main exhaust ejector. Compartment cooling air is provided by an opening in the bulkhead separating the engine compartment and inlet plenum, and is exhausted through the engine exhaust ejector system.

A free-stream ram inlet located atop the cabin surface provides cooling air for the accessory drives, the main transmission, and the annular oil cooler located integrally with the mixed-flow blower inlet. All cooling flows are processed by the large blower and pass through ducts into the plenum which surrounds each engine exhaust system. The higher pressure cooling air is injected into the main engine exhaust through slots for metal cooling and plume dilution. Hiding-turning vanes are located at the exhaust discharge to eliminate hot metal radiation effects.

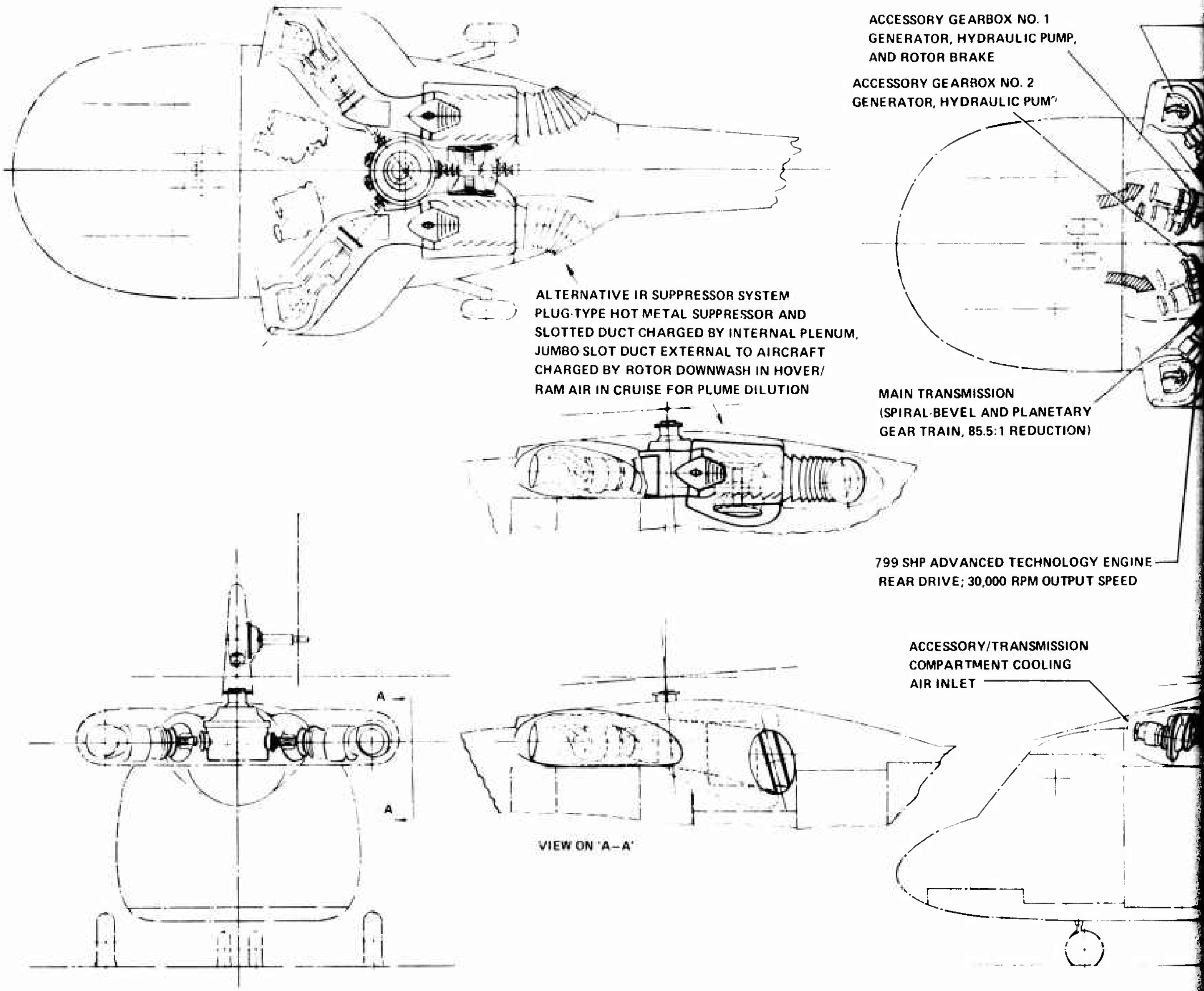
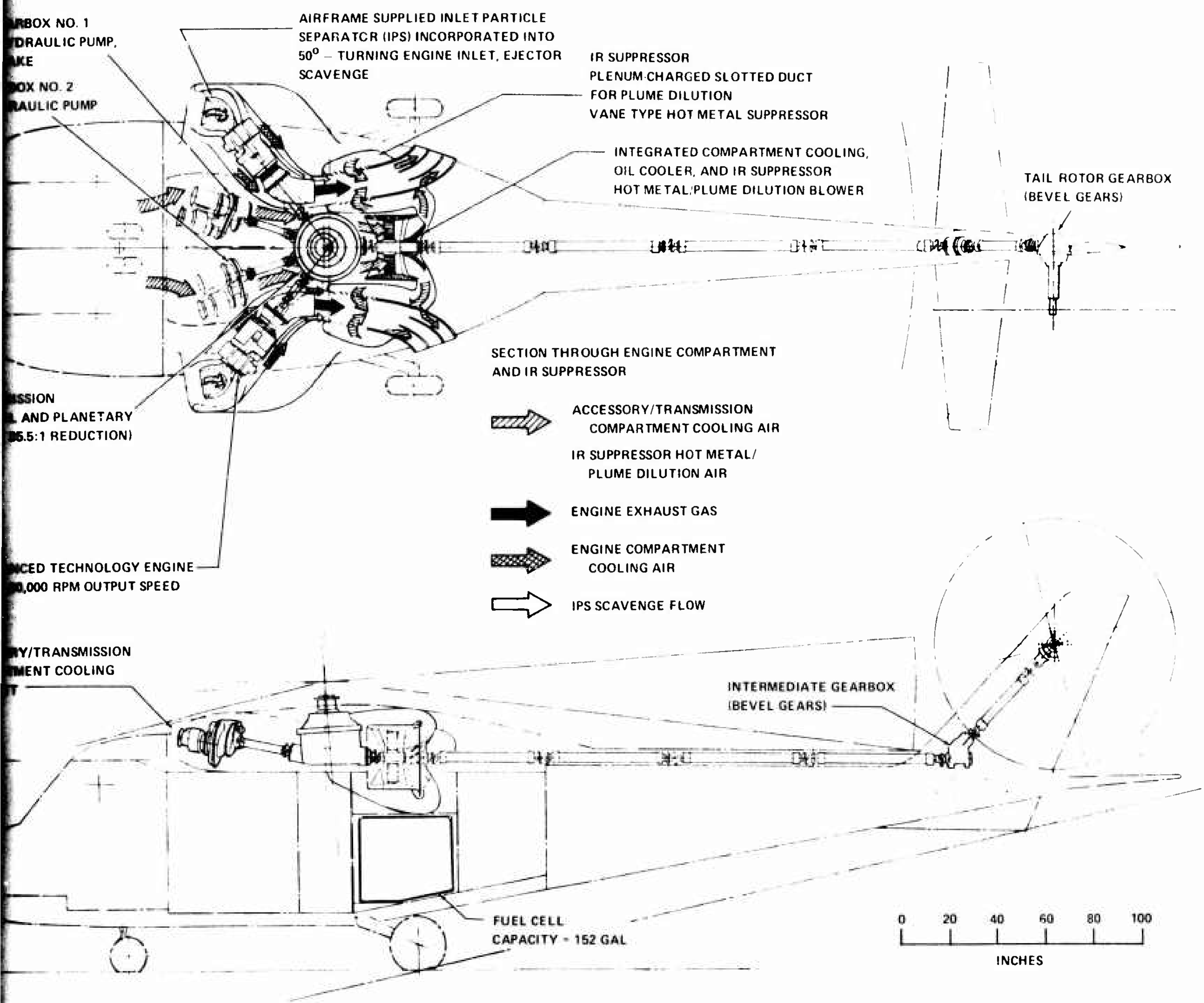


Figure 25. Concept f, Integrated Propulsion-Drive System Installation (Horizontal, Direct Rear-Drive Engines).



RBOX NO. 1
DRAULIC PUMP,
KE
OX NO. 2
AULIC PUMP
AIRFRAME SUPPLIED INLET PARTICLE SEPARATOR (IPS) INCORPORATED INTO 50° – TURNING ENGINE INLET, EJECTOR SCAVENGE
IR SUPPRESSOR
PLENUM-CHARGED SLOTTED DUCT FOR PLUME DILUTION
VANE TYPE HOT METAL SUPPRESSOR
INTEGRATED COMPARTMENT COOLING, OIL COOLER, AND IR SUPPRESSOR HOT METAL/PLUME DILUTION BLOWER
TAIL ROTOR GEARBOX (BEVEL GEARS)
SSION
AND PLANETARY
5.5:1 REDUCTION)
SECTION THROUGH ENGINE COMPARTMENT AND IR SUPPRESSOR
ACCESSORY/TRANSMISSION COMPARTMENT COOLING AIR
IR SUPPRESSOR HOT METAL/ PLUME DILUTION AIR
ENGINE EXHAUST GAS
ENGINE COMPARTMENT COOLING AIR
IPS SCAVENGE FLOW
CED TECHNOLOGY ENGINE
0,000 RPM OUTPUT SPEED
Y/TRANSMISSION
MENT COOLING
INTERMEDIATE GEARBOX (BEVEL GEARS)
FUEL CELL
CAPACITY - 152 GAL
0
20
40
60
80
100
INCHES

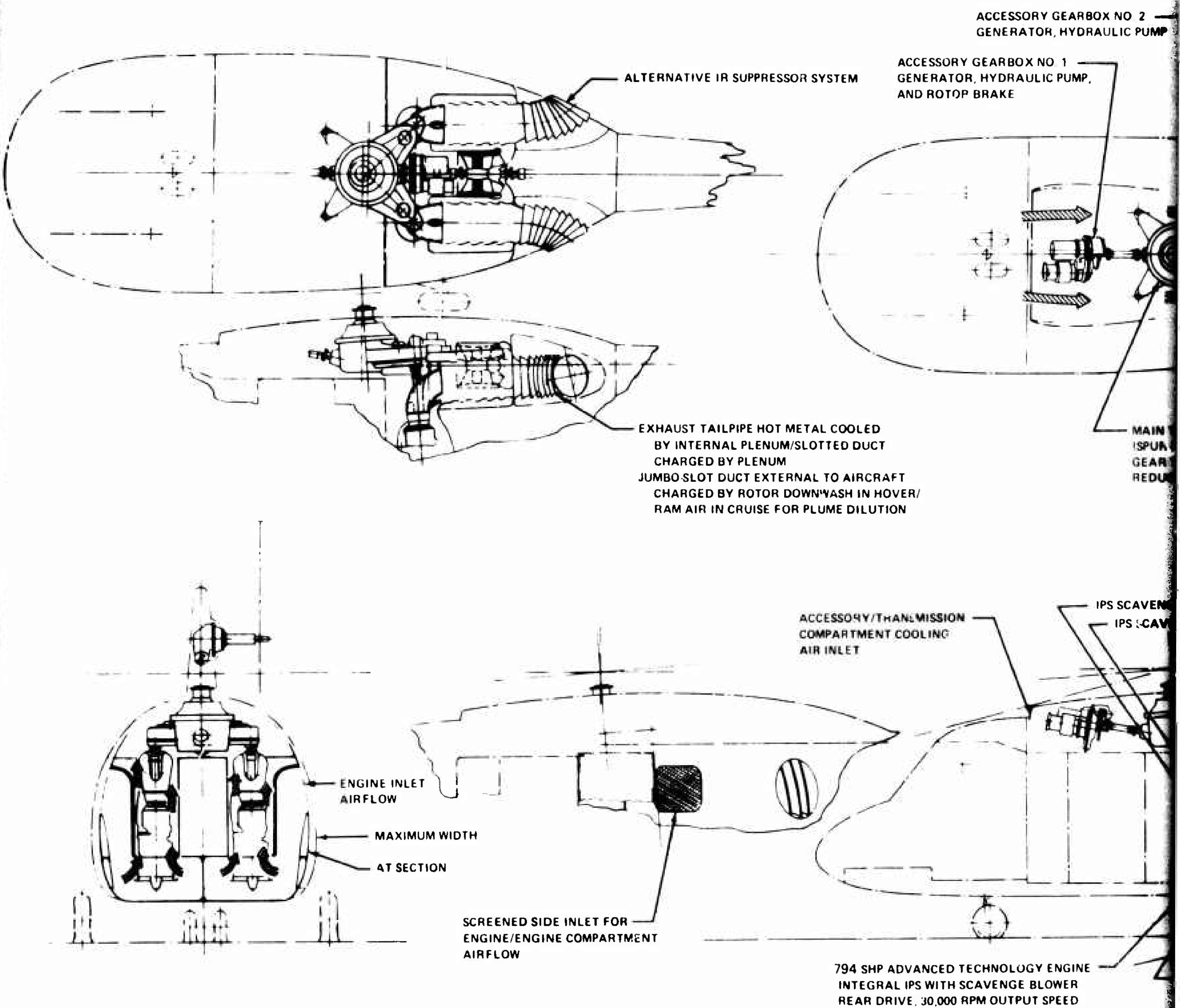


Figure 26. Concept g, Integrated Propulsion-Drive System Installation (Vertical, Rear-Drive Engines).

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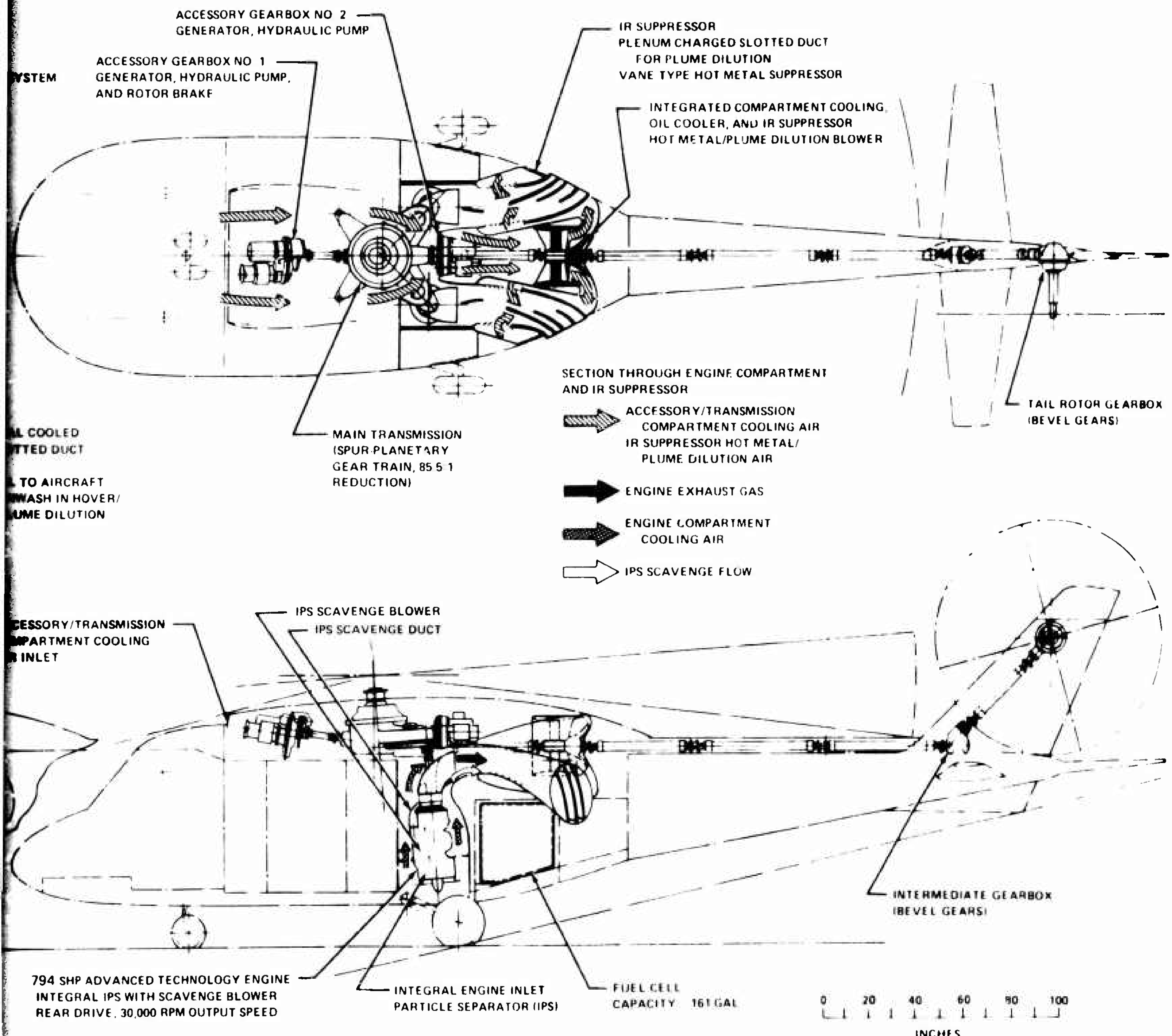

ACCESSORY GEARBOX NO 2
GENERATOR, HYDRAULIC PUMP
ACCESSORY GEARBOX NO 1
GENERATOR, HYDRAULIC PUMP, AND ROTOR BRAKE
YSTEM
IR SUPPRESSOR
PLENUM CHARGED SLOTTED DUCT FOR PLUME DILUTION
VANE TYPE HOT METAL SUPPRESSOR
INTEGRATED COMPARTMENT COOLING, OIL COOLER, AND IR SUPPRESSOR HOT METAL/PLUME DILUTION BLOWER
SECTION THROUGH ENGINE COMPARTMENT AND IR SUPPRESSOR
TAIL ROTOR GEARBOX (BEVEL GEARS)
L COOLED
TTED DUCT
MAIN TRANSMISSION (SPUR-PLANETARY GEAR TRAIN, 85.5:1 REDUCTION)
ACCESSORY/TRANSMISSION COMPARTMENT COOLING AIR
IR SUPPRESSOR HOT METAL/ PLUME DILUTION AIR
TO AIRCRAFT
WASH IN HOVER/
UME DILUTION
ENGINE EXHAUST GAS
ENGINE COMPARTMENT COOLING AIR
IPS SCAVENGE FLOW
ESSORY/TRANSMISSION
PARTMENT COOLING
INLET
IPS SCAVENGE BLOWER
IPS SCAVENGE DUCT
INTERMEDIATE GEARBOX (BEVEL GEARS)
794 SHP ADVANCED TECHNOLOGY ENGINE
INTEGRAL IPS WITH SCAVENGE BLOWER
REAR DRIVE, 30,000 RPM OUTPUT SPEED
INTEGRAL ENGINE INLET PARTICLE SEPARATOR (IPS)
FUEL CELL CAPACITY 161 GAL
0 20 40 60 80 100
INCHES

tallation

Forward and aft accessory gearboxes are incorporated as in the baseline aircraft. The blower is integral with the tail rotor drive through the aft AGB. A conventional antitorque tail rotor system is employed for this configuration. The overall dimensions of the aircraft, including the fixed cabin dimensions, remain the same as the baseline aircraft.

An alternate variation shown in Figure 26 offers a smaller centrifugal blower and uses rotor downwash in conjunction with a "jumbo-slot" exhaust duct to film cool the end of the duct with additional plume dilution.

This scheme is similar to the system employed in the alternate version of the horizontal, direct rear-drive engine concept. Since hiding-turning vanes are not employed, the engine exhaust tail pipe (which also turns the hot exhaust gas) must be convection cooled with air from the centrifugal blower to maintain hot metal temperature within the required IR radiation levels.

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CONFIGURATION EVALUATION

Comparative analyses and evaluations of the baseline aircraft and of the advanced aircraft with integrated airflow concepts were conducted to include:

- Performance
- Weight
- Complexity
- Design
- Technical risk
- Control requirements

In the following paragraphs, weight and performance parameters used in the comparative analyses are quantified, and factors considered in comparing complexity, design, technical risk, and control requirements are discussed qualitatively. The procedure used to determine the relative importance of each of these evaluation criteria is discussed in Appendix B. Also shown are the factors used in the selection of the three most promising concepts.

AIRCRAFT SYSTEM WEIGHT

The results of the weight analysis are summarized in Table 6. As indicated, the baseline aircraft represents the lowest weight empty of all the configurations evaluated. In contrast, the heaviest vehicle is the fan-in-fuselage concept which weighs 450 lb more than the baseline. This increase in weight is attributable to the body weight, which results from the heavy tail section. The IR suppressor unit for the horizontal, front-drive concept (b) is considered as an add-on unit to the baseline, with the integrated airflow management cooling air fan and ducts the major items that contribute to the increased weight empty of this concept.

The increased weight empty of the vertical, front-drive concept (d) over the baseline aircraft is primarily due to its larger main transmission. This concept incorporates IR suppression ducting and centrifugal blower which also result in increased weight.

The significant items which tend to increase the weight empty for the rear-drive concept (e) are the engine gearbox, armor, and IR suppressor blower and ducting.

TABLE 6. CONCEPT EVALUATION - AIRCRAFT WEIGHT SUMMARY

Concept	a Baseline	b Horizontal Front Drive	c Fan-in-Fuselage	d Vertical Front Drive	e Horizontal Rear Drive	f Horizontal Direct Drive	f Horizontal Direct Drive Alt.	g Vertical Rear Drive	g Vertical Rear Drive Alt.
Rotor	888	888	888	888	888	888	888	888	888
Tail	153	153	130	153	153	153	153	153	153
Surfaces	113	113	130	113	113	113	113	113	113
Rotor	40	40	0	40	40	40	40	40	40
Body	760	760	886	793	760	760	760	793	793
Alighting Gear Group	245	245	245	245	245	245	245	245	245
Engine Section	98	95	95	122	118	127	127	137	137
Propulsion Group	1695	1947	2045	1895	1981	1982	1999	1900	1907
Engine	430	430	430	430	430	430	430	430	430
Exhaust System/ IRS	5	177	10	10	10	10	10	10	10
Ducts, etc.	0	43	293	170	180	276	304	167	185
Controls	17	17	17	17	17	17	17	17	17
Starting	140	140	140	140	140	140	140	140	140
Fan		23	199	23	34	23	12	23	12
Lubricating	1	1	1	1	1	1	1	1	1
Fuel	172	172	172	172	172	172	172	172	172
Drive System	930	944	783	932	997	913	913	940	940
Engine Xmsns	116	116	116	0	172	0	0	0	0
Main Xmsn	514	514	514	645	514	594	594	645	645
Interm. Xmsn	34	34	0	34	34	34	34	34	34
Tail Rotor Xmsn	74	74	0	74	74	74	74	74	74
AGBs	97	91	103	97	91	91	91	97	97
Cooler/Blower	26	20	20	20	20	20	20	20	20
Armor	7	30	0	0	30	30	30	0	0
Shafting	62	65	30	62	62	70	70	70	70
Flight Controls	592	592	592	592	592	592	592	592	592
Fixed Equipment*	1476	1476	1476	1476	1476	1476	1476	1476	1476
Weight Empty	5907	6156	6357	6164	6213	6223	6240	6184	6191
Crew	470	470	470	470	470	470	470	470	470
Trapped Liquids	10	10	10	10	10	10	10	10	10
Engine Oil	26	26	26	26	26	26	26	26	26
Payload	960	960	960	960	960	960	960	960	960
Fuel	1127	878	677	870	821	811	794	850	843
Gross Weight	8500	8500	8500	8500	8500	8500	8500	8500	8500

* Fixed Equipment List:

Instruments	142	
Hydr. & Penumatic	50	
Electrical Group	200	
Avionics Group	466	
Armament Group	38	
Furn. & Equip. Group	468	
Accom. For Person.		312
Misc. Equipment		57
Furnishings		43
Emerg. Equipment		56
ECU	40	
Anti-Icing Group	36	
Load & Handling Group	36	
	1476	

Elimination of the engine gearbox in the direct rear-drive concept does not offset the weights of the main gearbox, armor, IR blower and ducting, and engine nacelle, which results in an aircraft with a weight empty in excess of the baseline. The vertical rear-drive aircraft possesses a heavier body, engine section and main transmission than the baseline.

SYSTEM PERFORMANCE

The performance capabilities of the baseline aircraft were evaluated on the basis of mission radius and vertical rate of climb. All aircraft were evaluated at a constant gross weight and payload. The performance capabilities of the aircraft are compared in Table 7. As noted, the horizontal, front-drive concept (b) possesses the longest mission radius of all the advanced configurations. This is a direct reflection of the lower weight empty of the aircraft, which permitted configuring it with a larger fuel capacity. Table 7 indicates that the fan-in-fuselage configuration possessed the highest vertical climb capability of all the advanced configurations, exceeding most configurations by approximately 200 fpm. The alternate version of the direct, rear-drive configuration and the alternate vertical, rear-drive configuration were second and third, respectively. The superior climb performance of the fan-in-fuselage concept is attributable to the elimination of the tail rotor and its replacement by a blower system. The improved vertical climb capabilities of the direct, rear-drive and vertical, rear-drive alternate configurations are attributable to the reduction of accessory blower power in both these configurations.

Drag

Table 8 contains the component drag breakdown of each of the study configurations. As indicated, all configurations are within two square feet of one another. The highest drag is possessed by both the direct, rear-drive and vertical, rear-drive alternate configurations. This increased drag is attributable to the exhaust issuing from the jumbo slot arrangement on these configurations. Since the drag for most configurations is comparable, mission range as previously noted is a direct function of fuel capacity, which varies inversely as the weight empty.

Aircraft drag was determined from a detailed analysis of a 1/10th scale layout of each of the configurations. Wetted and

TABLE 7. CONCEPT EVALUATION - PERFORMANCE SUMMARY (DGW = 8500 LB, PL = 960 LB)

Concept	a Baseline	b Horizontal Front Drive	c Fan-in-Fuselage	d Vertical Front Drive	e Horizontal Rear Drive	f Horizontal Direct Drive	f Alternate	g Vertical Rear Drive	g Alternate
Weight Empty - lb	5907	6156	6357	6164	6213	6223	6240	6184	6191
Mission Fuel Avail. - lb	1127	878	677	870	821	811	794	850	843
Mission Radius									
Primary Mission - NM	50	10	-22	2	0	0	0	4	5
Radius Mission - NM	154	111	72	101	99	98	96	103	103
Vertical Climb Capability - fpm at DGW, 4000 ft/95°F, 95 Percent IRP	555	145	385	95	45	145	370	95	325
Net Power Available at 4000 ft/95°F, 95 Percent IRP	1052	971	1017	962	952	971	1016	962	1007

Primary Mission:
- HOGE 15 Min at 4000 ft, 95°F
- Cruise Out To <u>Mission Radius</u> at 140 kt, S.L./59°F
- Loiter 1 Hour at 70 kt, S.L./59°F
- Cruise in at 140 kt, S.L./59°F
- 30 Min Reserve at 140 kt, S.L./59°F
- Entire Mission Flown With Payload

Radius Mission
- Warm up 2 Min at MCP
- Cruise Out To <u>Mission Radius</u> at 140 kt
- Land, Unload Payload
- Warm up 2 Min at MCP
- Cruise in at 140 kt
- Reserve = 10 Percent of Initial Fuel
- Mission Flown at 4000 ft/95°F

TABLE 8. CONCEPT EVALUATION - COMPONENT DRAG BUILDUP

Concepts	Equivalent Flat Plate Area, f_e - sq ft								
	a Baseline	b Horizontal Front Drive	c Fan-in-Fuselage	d Vertical Front Drive	e Horizontal Rear Drive	f Horizontal Direct Drive	f Alt.	g Vertical Rear Drive	g Alt.
Fuselage	1.66	1.65	1.93	1.76	1.64	1.64	1.56	1.73	1.65
Main Rotor Pylon	.21	.23	.56	.54	.66	.46	.46	.33	.33
Engine Nacelles	.27	.28		-		.48	.48	-	-
Inlets	.18	.19	.41	.22	.18	.19	.19	.23	.23
Bellows Exhaust	-	-	-	-	-	-	1.80	-	1.80
Engine Momentum	.04	.04	.04	.04	.04	.04	.04	.04	.04
Ductwork	-	-	.50	-	-	-	-	-	-
Vertical Tail	.26	.26	1.18	.37	.26	.26	.26	.26	.26
Horizontal Tail	.26	.26	.27	.26	.26	.26	.26	.26	.26
Tail Rotor Assembly	.86	.86	-	.86	.86	.86	.86	.86	.86
T.R.-Fin Interference	.06	.06	-	.06	.06	.06	.06	.06	.06
Hub	3.57	3.57	3.57	3.57	3.57	3.57	3.57	3.57	3.57
Landing Gear	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31
Protuberances	.91	.91	.91	.91	.91	.91	.91	.91	.91
Trim Requirements	.34	.34	.34	.34	.34	.34	.34	.34	.34
Total	11.93	11.96	13.02	12.24	12.09	12.38	14.10	11.90	13.62

projected areas for the basic arrangements were determined with a planimeter, and the major aircraft components were evaluated separately. The equivalent drag includes the drag due to cooling flow, momentum loss, trim and interference effects. The momentum drags associated with the external airflows are schematically shown in Figure 27.

Climb Performance

Table 9 illustrates the power breakdown at a vertical rate of climb of 500 fpm for the baseline and advanced concepts. As illustrated, the fan of the fan-in-fuselage configuration incorporates both the antitorque and IR suppression functions and so results in the best power available, thereby providing a significant climb advantage of this aircraft. However, the added weight required for this concept would offset this advantage if the aircraft were sized to perform a given mission.

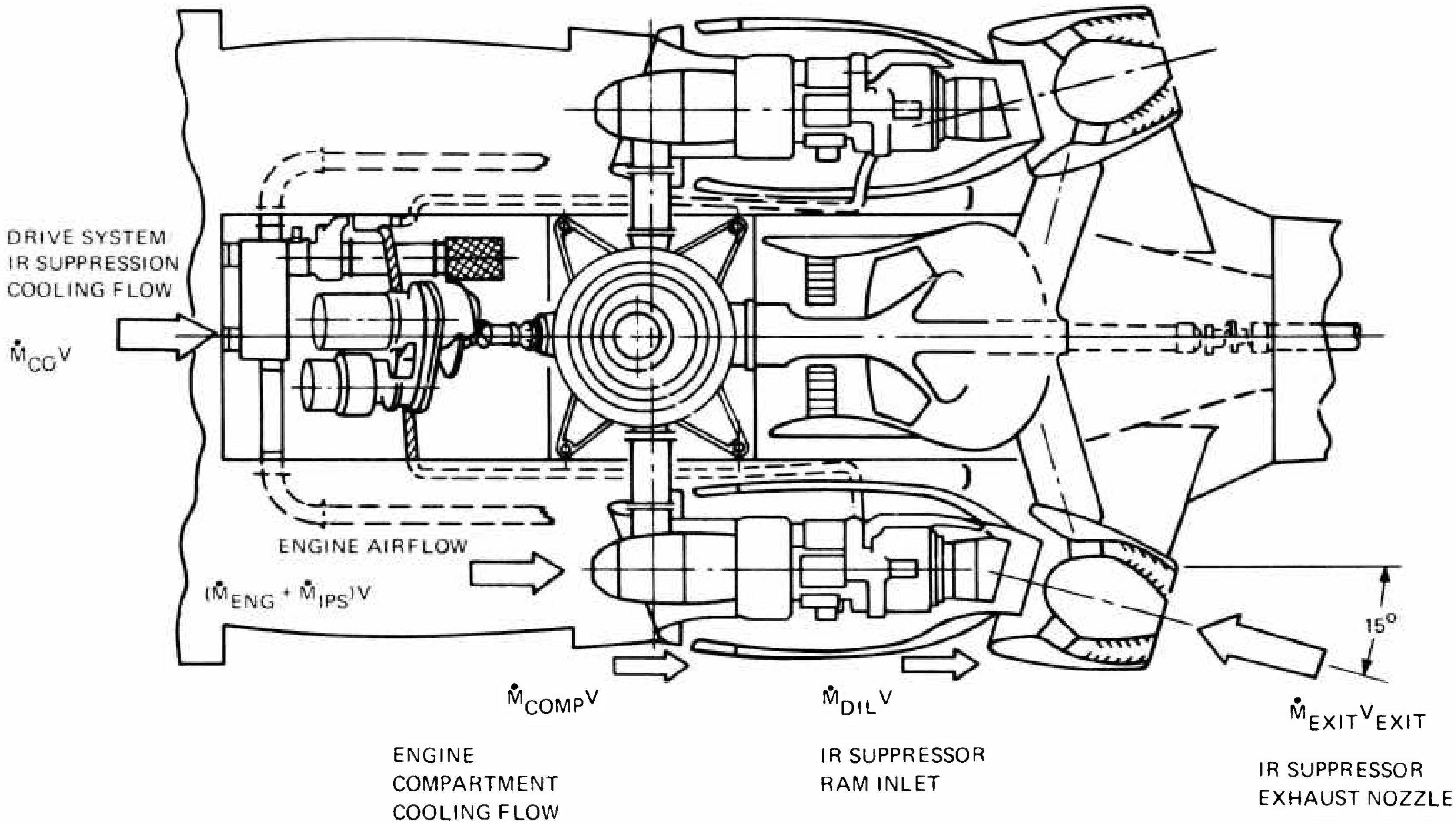
SYSTEM COMPLEXITY

The factors considered in the evaluation of the system complexity of the baseline and advanced integration concepts include:

- o Number of subsystems and components
- o Number of transmissions and bevel gear meshes
- o Effect of complexity on reliability and maintainability (R&M)
- o Effect of complexity on subsystem simplicity and producibility

Some of the key points noted during the evaluation are summarized below:

- o The vertical, front-drive concept provides the minimum complexity as a result of the reduction in number of transmissions utilized in this configuration and the elimination of the bevel gears in the main rotor drive.
- o The horizontal, front-drive concept is superior to the baseline with respect to the integrated airflow system utilized on this concept.



$$\text{MOMENTUM DRAG} = (\dot{M}_{CO}V + \dot{M}_{ENG}V + \dot{M}_{COMP}V + \dot{M}_{DIL}V + \dot{M}_{IPS}V) - \dot{M}_{EXIT}V_{EXIT}\cos(15^{o})$$

Figure 27. Momentum Thrust/Drag Components of Propulsion Integration Airflows.

TABLE 9. CONCEPT EVALUATION - POWER REQUIRED FOR 500-FPM VERTICAL RATE OF CLIMB

Concept	a Baseline	b Horizontal Front Drive	c Fan-in-Fuselage	d Vertical Front Drive	e Horizontal Rear Drive	f Horizontal Direct Drive	f Alternate	g Vertical Rear Drive	g Alternate
Main Rotor Hover Power	861	861	861	861	861	861	861	861	861
Main Rotor Climb Power	84	84	84	84	84	84	84	84	84
Tail Rotor Power	96	96	-	96	96	96	96	96	96
Main-Tail Rotor Power Required*	1041	1041	945	1041	1041	1041	1041	1041	1041
Integrated Blower Power	0	90	139	90	100	90	45	90	45
Transmission Loss	27	27	28	27	27	27	27	27	27
Accessory Power	25	25	25	25	25	25	25	25	25
Total Power Required at 500 fpm	1093	1183	1128	1183	1193	1183	1138	1183	1138
Engine Power Available**	1104	1113	1113	1104	1104	1113	1113	1104	1104
Net Power Available	1052	971	1017***	962	952	971	1016	962	1007

* Power Required for 500-fpm Vertical Climb Capability.

** 95 Percent IRP at 4000 ft/95°F. Configurations a, e, g, and g **alt.** include IPS blower loss of 9 hp.

*** Net power available for the fan-in-fuselage assumes that the blower loss is equivalent to the difference between blower power and an equivalent **antitorque** power of 96 hp (1113-43-28-25 = 1017 shp).

- The horizontal, rear-drive configuration is deemed the most complex system due to its separate overboard engine IPS blower system and integrated, dual-element IR ducted fan.

- The variable pitch fan-louvered antitorque system on the fan-in-fuselage configuration presents maintainability problems.

AIRCRAFT SYSTEM DESIGN

Factors considered during the evaluation of aircraft system design include:

- The impact on transportability of aircraft external dimension and configuration changes.

- Effect of engine installation design on inlet ingestion susceptibility, inlet flow uniformity, and cockpit and cabin noise level.

- Vulnerability and survivability.

- On-off capability of the IR suppressor concepts (impact on installed engine power).

- Safety and human factors.

The system design baseline aircraft suffered by comparison with some of the advanced concepts due to its lack of IR suppression capability. Incorporation of the IR suppressor in the horizontal, front-drive concept (b) provided this concept with the highest score.

The fan-in-fuselage concept compared favorably with concept (b) because of its improved IR capability and the safety features of the antitorque design. Reference 5 emphasizes the safety aspects of this concept, which reduces the hazard to personnel in the area of the tail rotor and eliminates the problem of

(5) C. R. Akeley and G. W. Carson, FAN-IN-FUSELAGE ADVANCED ANTITORQUE SYSTEM, Kaman Aerospace Corporation; USAAMRDL Technical Report 74-89, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, November 1974, AD A005049.

aircraft damage caused by the tail rotor impacting ground objects. The latter benefit has a substantial effect on aircraft system R&M characteristics. In addition, as noted in the Reference 5 system study, the fan-in-fuselage configuration offers the additional benefits of reduced radar and/or noise detection. With suitable vectoring concepts, the fan-in-fuselage could provide forward thrust augmentation in cruise flight. However, this auxiliary thrust is advantageous only if higher aircraft speed is desired. At the 140-knot cruise speed of the utility helicopter, the propulsive efficiency of the ducted fan is significantly lower than the efficiency of the main rotor. Consequently, there would be a power penalty associated with fan auxiliary thrust.

The low system evaluation score given the vertical, front drive is attributed to the increase in the aircraft dimensional envelope, poor transportability, engine exhaust location and engine noise in the cabin. The direct, rear-drive concept also suffered from an increase in the aircraft dimensional envelope. In addition, the vulnerability of the outboard engine location penalized this configuration.

TECHNICAL RISK

The system requirements stipulated that drive system technology be consistent with the state of the art as proven by component demonstration, and that aircraft rotor system, structure, and materials be consistent with current design techniques as refined by 1980. Consequently, the technical risk evaluation was concerned only with the IR suppression system, and the antitorque system in the fan-in-fuselage concept.

Scoring for technical risk was highest with substantially "O" risk (used on production aircraft). Listed below are the risk assessment and major factors considered for each concept.

- Baseline - "O" risk
- Horizontal, front drive and vertical, front drive - low risk (IR suppression concept proven by component development)

- Fan-in-fuselage - moderate risk (fan-in-fuselage antitorque concept within development state of the art)

- Horizontal, rear drive - high risk due to dual-element fan

- Alternate version of direct, rear drive and vertical, rear drive - high risk due to jumbo slot duct concept and rotor downwash exhaust plume dilution.

CONTROL REQUIREMENTS

Dynamic system compatibility and subsystem control requirements were considered during all the advanced concept studies but were not weighted heavily in the selection criteria. An integrated blower separate from the tail rotor drive system provided the vertical, front-drive arrangement with the highest score, which compared favorably with the baseline. The fan-in-fuselage concept with its variable pitch ducted fan and louvered antitorque system, scored the lowest with regard to dynamic system compatibility as well as its need for increased control requirements.

Horizontal, front-drive and alternate direct, rear-drive and vertical, rear-drive arrangements represent the mean with regard to the control requirements.

CONCEPT SELECTION

On the basis of comparative analyses and evaluations of the items previously discussed, three advanced concepts which offered the most potential for meeting system requirements with the minimum adverse effect on the aircraft were selected for preliminary design. The advanced concepts selected include:

- Horizontal, front-drive - pod-mounted engines, transmission-driven blower for integrated flows, with conventional tail rotor.

- Vertical, front-drive - buried engines, direct-drive into transmission, transmission-driven blower for integrated flows, with conventional tail rotor.

- Direct, rear-drive (alternate) - splayed, sponson-mounted engines, rear direct-drive into transmission, transmission-driven blower for integrated flows, with conventional tail rotor.

The procedure used to determine the relative importance of each of the areas of evaluation is presented in Appendix B, and the weighting factors were as follows:

	Weighting Factor
o Aircraft system performance	5
o System weight	3
o System complexity	4
o System design	3
o Technical risk	1
o Control requirements	1

Table B-2 of Appendix B shows the comparison of all concepts relative to the baseline.

CONVENTIONAL AIRCRAFT PRELIMINARY DESIGN

The preliminary design effort encompassed a more comprehensive structural design of the aircraft, integration of the engines and drive train with the aircraft structure, preparation of three-view drawings of the aircraft, and an iteration of the subsystem weights to define more accurately aircraft weight empty. The impact of a current IR suppressor on the design of the baseline configuration also was determined. A detailed breakdown of subsystem weights contributing to weight empty was prepared for both the baseline aircraft and the baseline with current IR suppressor according to MIL-STD-1374, Part 1 (see Appendix C).

Figure 28 illustrates the baseline aircraft structural design concept and the integration of the conventional propulsion and drive system into the airframe. The aircraft incorporates a pod-mounted horizontal and parallel front-drive version of the advanced-technology engines. The engine transmission is mounted on the engine front frame and incorporates a right-angle, bevel-gear drive into the main rotor transmission. The conventional main transmission consists of a spiral-bevel collector gear and a one-stage planetary gear. A bevel gear driven by the collector drives the tail rotor shaft to the bevel gear intermediate transmission, and from there another shaft drives the bevel-gear tail rotor transmission and the tail rotor.

Nose gearboxes provide both the initial reduction of 2.7:1 from the engine output shaft speed of 30,000 rpm to 11,100 rpm, and a right-angle change in direction inboard to the main rotor transmission. An integral overrunning clutch is located on the output side of the engine nosebox. The engine mounted gearbox and integral lubrication system are supported from the front mounting face of the engine.

The main rotor transmission has a 5.83:1 bevel gear reduction and a 5.43:1 single-stage planetary reduction to achieve 351 rpm rotor speed. An accessory gearbox which incorporates a rotor brake is attached to the forward face of the main rotor transmission at the centerline of the aircraft. An auxiliary gearbox, to provide redundant electrical and hydraulic power, and the tail rotor drive are attached to the aft

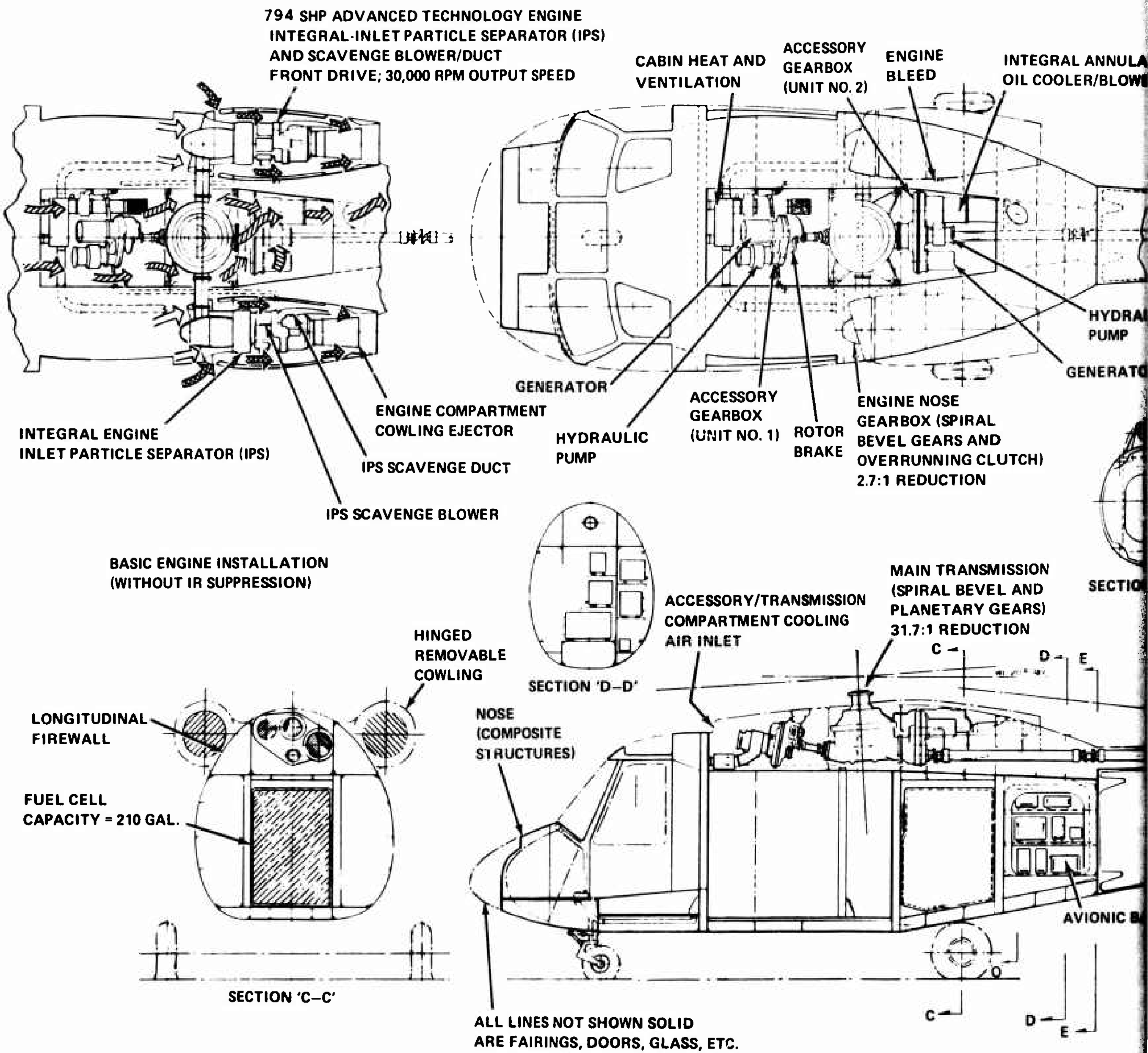
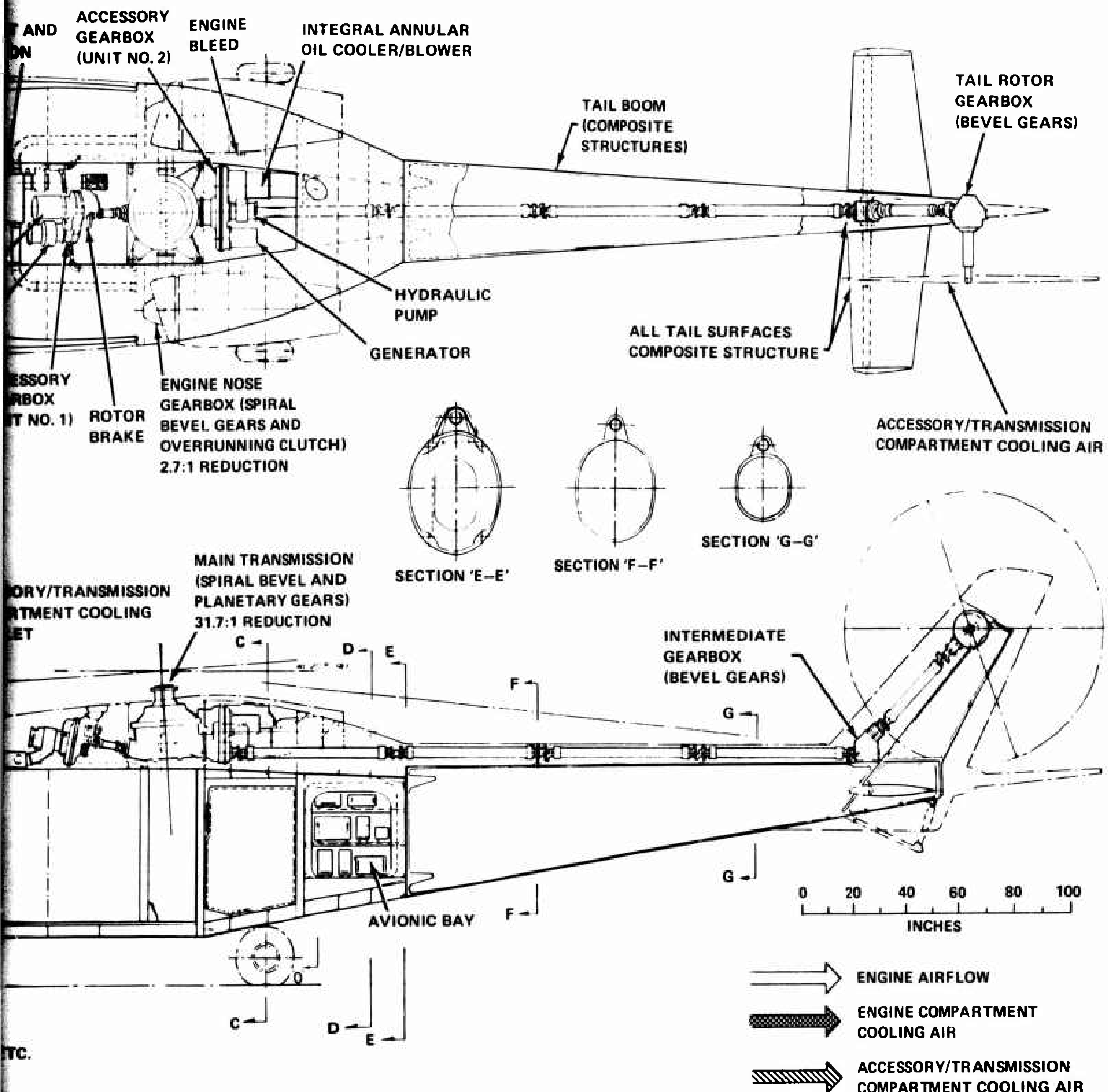


Figure 28. Preliminary Design and Propulsion Installation Drawing of Concept a, Baseline Aircraft.



T AND
ON
ACCESSORY GEARBOX (UNIT NO. 2)
ENGINE BLEED
INTEGRAL ANNULAR OIL COOLER/BLOWER
TAIL BOOM (COMPOSITE STRUCTURES)
TAIL ROTOR GEARBOX (BEVEL GEARS)
HYDRAULIC PUMP
GENERATOR
ALL TAIL SURFACES COMPOSITE STRUCTURE
ESSORY RBOX T NO. 1)
ROTOR BRAKE
ENGINE NOSE GEARBOX (SPIRAL BEVEL GEARS AND OVERRUNNING CLUTCH) 2.7:1 REDUCTION
ACCESSORY/TRANSMISSION COMPARTMENT COOLING AIR
SECTION 'E–E'
SECTION 'F–F'
SECTION 'G–G'
MAIN TRANSMISSION (SPIRAL BEVEL AND PLANETARY GEARS) 31.7:1 REDUCTION
ORY/TRANSMISSION RTMENT COOLING ET
INTERMEDIATE GEARBOX (BEVEL GEARS)
C
D
E
F
G
AVIONIC BAY
0 20 40 60 80 100
INCHES
ENGINE AIRFLOW
ENGINE COMPARTMENT COOLING AIR
ACCESSORY/TRANSMISSION COMPARTMENT COOLING AIR

TC.

rawing

face of the main rotor transmission. The drive shaft to the intermediate transmission operates at 7100 rpm, the series of bevel gear meshes with the main transmission collector gear providing a ratio of 3.73:1. The intermediate and tail rotor transmissions provide the additional reduction to drive the tail rotor at 1770 rpm. Figure 29 illustrates schematically the gear ratios throughout the drive system.

The lubrication system for the main rotor transmission consists of a primary and a backup system which is in continuous operation. An integral annular oil cooler is used with an axial fan, driven from the aft accessory gearbox, supplying the necessary cooling air. The separate backup system does not have the integral cooler, but does have its own pump, screen, reservoir, passages, and pressure sensing diagnostic system. The dry sump in the main transmission is scavenged from four locations to accommodate all flight attitudes. The dry sump is armored against a 7.62-mm ballistic strike and minimizes the damage effects from an impact with a 23-mm projectile.

The main transmission is sized for 80 percent of the total two-engine installed intermediate power (sea level/59°F), 1293 shp. This represents an 18-percent margin over the power required to climb 500 fpm at 4,000 feet, 95°F. The tail rotor drive system rating is 139 shp, a 42-percent margin over the tail rotor power required at the climb condition.

The final weight and performance analysis of the baseline aircraft showed a slight increase in weight empty from the 5907 lb calculated in the CONCEPTUAL ANALYSES to 5927 lb, which resulted in a decrease in the design primary mission radius to 43 NM. The 20-lb adjustment in weight was concentrated in the body weight. The vertical rate-of-climb capability for the baseline aircraft at 4000 feet, 95°F and 95 percent IRP is 536 fpm.

The baseline aircraft was configured to incorporate current technology IR suppressor units (see Figure 30). These units are based on the technology demonstrated with a hot-metal IR suppressor on the CH-46 aircraft, and a plug-type ram ejector IR suppressor unit under development for the YUH-61A UTTAS.

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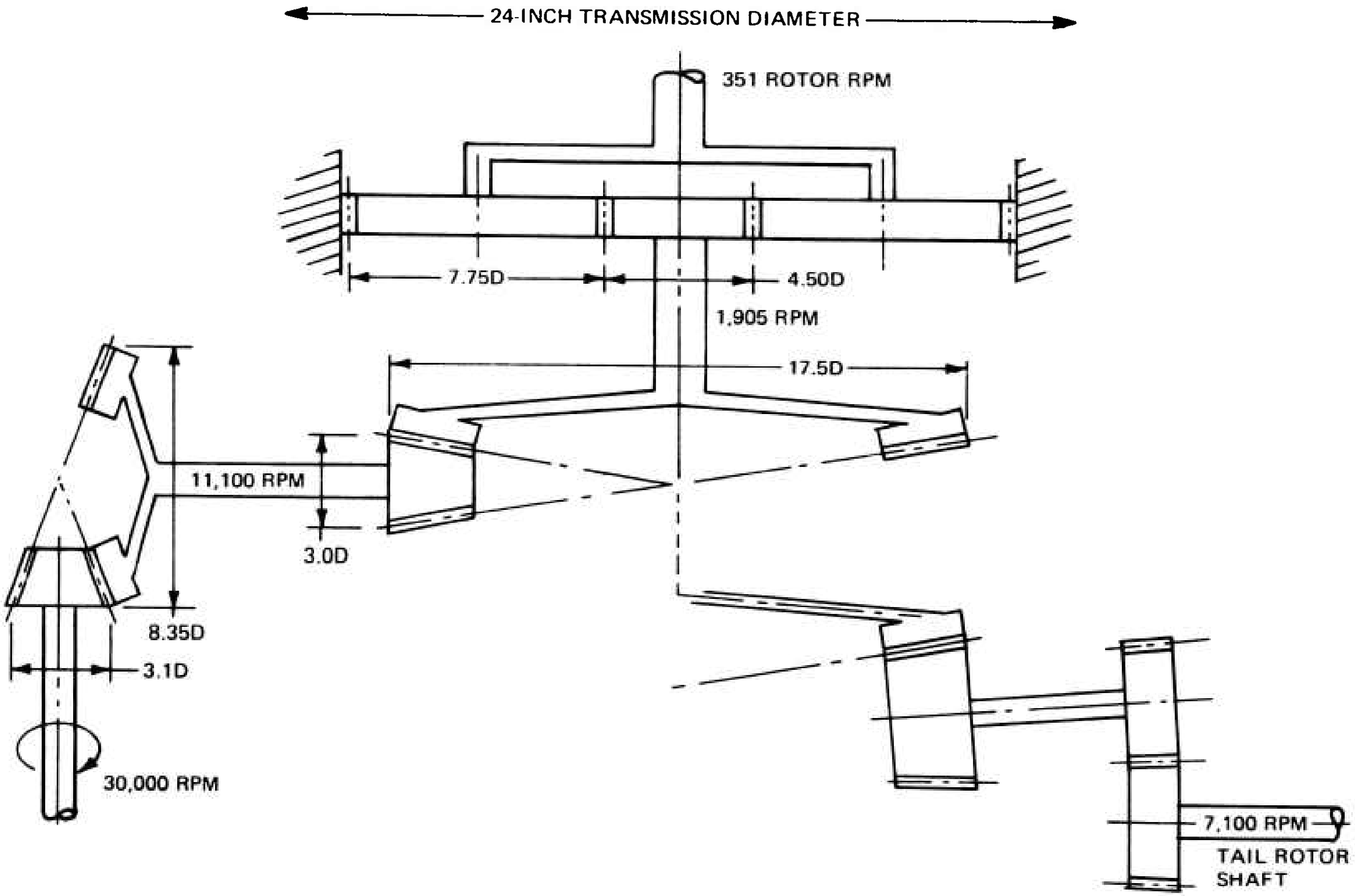


Figure 29. Baseline Drive System Gear Reductions and Shaft Speeds.

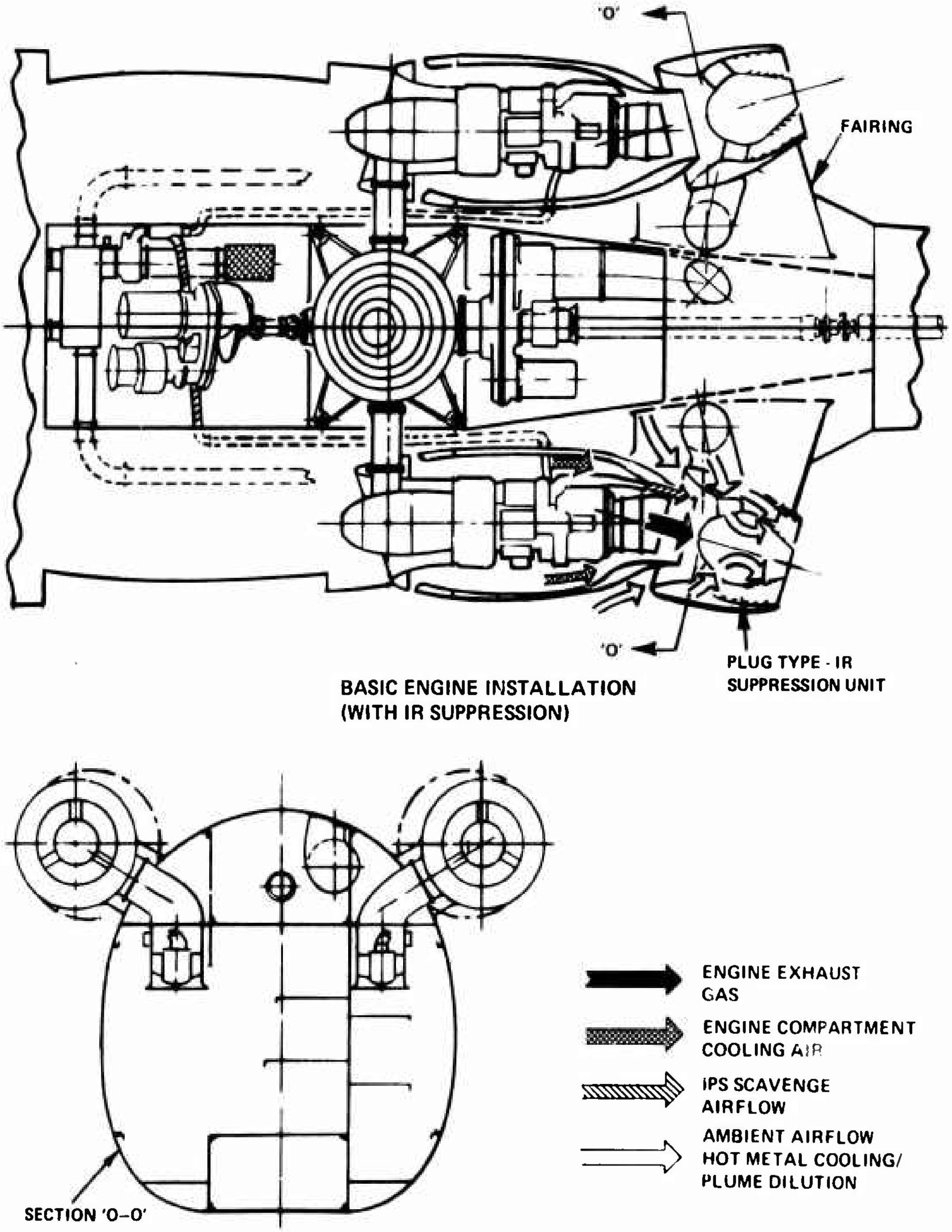


Figure 30. Current IR Suppressor Design for Baseline Aircraft, Concept a.

Current state-of-the-art IR suppression unit design will provide for hot metal shielding with suppressor surfaces cooled to the levels defined in Figure 18. These requirements dictated the following blower design (at 4000 feet, 95°F):

Airflow	= 1.0 lb/sec
Pressure Rise	= 24. in. water
Blower Hydraulic Motor Power	= 6.5 shp
Diameter	= 9.0 in.
Accessory Hydraulic Power	= 7.5 shp

To meet this added hydraulic power demand on the baseline aircraft, the capacity of the hydraulic power supply unit on the aft accessory gearbox was increased with a subsequent increase in the accessory power requirements. Hydraulic lines, with cockpit operated solenoid valves if desired for on/off capability, are connected to the isolated IR unit blowers. These blowers are located immediately outside the upper deck buttline beam structure and adjacent to the IR units, to minimize the length of cooling air ductwork and, as required, provide forced ventilation to the avionics bays and compartments.

Calculations of the performance of the current IR suppressor design are summarized in Appendix A. The hydraulic blower was sized to provide adequate airflow for the hot metal cooling in the aft section of plug-suppressor unit, to maintain the exposed hot metal (i.e., line-of-sight) surfaces to 275°F. The engine exhaust and the hot metal cooling air are discharged in a manner which provides effective ejector action. The IPS blower discharge, compartment cooling air, and hot metal cooling air all coalesce to provide exhaust plume dilution. This ejector action concurrent with the ram-inlet-ejector design provides augmentation of the exhaust plume dilution air by 0.90 lb/sec at static conditions. Airflow requirements at intermediate power (4000 ft/95°F) are listed below:

Engine Airflow	= 4.04 lb/sec @ 1100°F
IPS	= 0.74 lb/sec @ 140°F
Compartment Cooling	= 1.23 lb/sec @ 140°F
Ejector Augmentation	= 0.90 lb/sec @ 95°F
Hot Metal Cooling Air	= 1.00 lb/sec @ 110°F

Thermodynamic considerations indicate that an exhaust plume temperature of 642°F is expected with the above engine exhaust cooling flow rates. Figure 4 in the SUMMARY section of

this report illustrated graphically the level of IR signature suppression obtainable with the current IR suppressor design.

The addition of current-technology plug-type IR suppressor units adds 143 lb to the empty weight of the baseline aircraft, consisting of a minor adjustment in body weight, the major addition of the IR suppression hardware, and a change in fuel system weight due to the lower fuel load (Appendix C). Body weight increased by 8 lb. The weight increase due to the IR suppression system was 177 lb, but this incorporated 20 lb of hardware charged to the nacelle weight, so the net increase was 157 lb. The higher empty weight resulted in lower fuel weight and lower fuel system weight - a 22-lb decrease.

The hydraulic-powered IR blower adds 15 shp accessory power. Back pressure on the engine is increased by the ram-ejector suppressor which causes an additional power penalty of 9 shp for the two engines, or effectively 24 shp additional power penalty compared to the baseline aircraft. The increase in accessory power requirements reduces the aircraft vertical rate-of-climb capability by 119 fpm. In addition, the weight of the IR suppression system reduces the amount of available mission fuel, which results in a 21-NM reduction in radius.

In Figure 31 is plotted the net momentum thrust (momentum drag at higher flight speeds) of the installed engine in the baseline aircraft, with and without the IR suppressor. Included are the engine airflow and IPS scavenge flow, engine compartment cooling flow, and the hydraulic-powered blower and ram-ejector airflows for the IR suppressor. Net thrust/ram drag values for intermediate and maximum continuous power ratings (IRP and MCP) are plotted. The baseline tail pipe of the engine is sized to give a net momentum thrust at flight speeds beyond the 140-knot design value, but the ejector concept for compartment cooling reduces the crossover to 100 knots. With the IR suppressor added, part of the power penalties inherent in the engine back pressure and accessory blower power are offset by larger gross thrust at the suppressor exit, and a higher crossover speed is obtained. Also, the magnitude of the gross thrust is greater throughout due to the blower airflow and suppressor ram airflow.

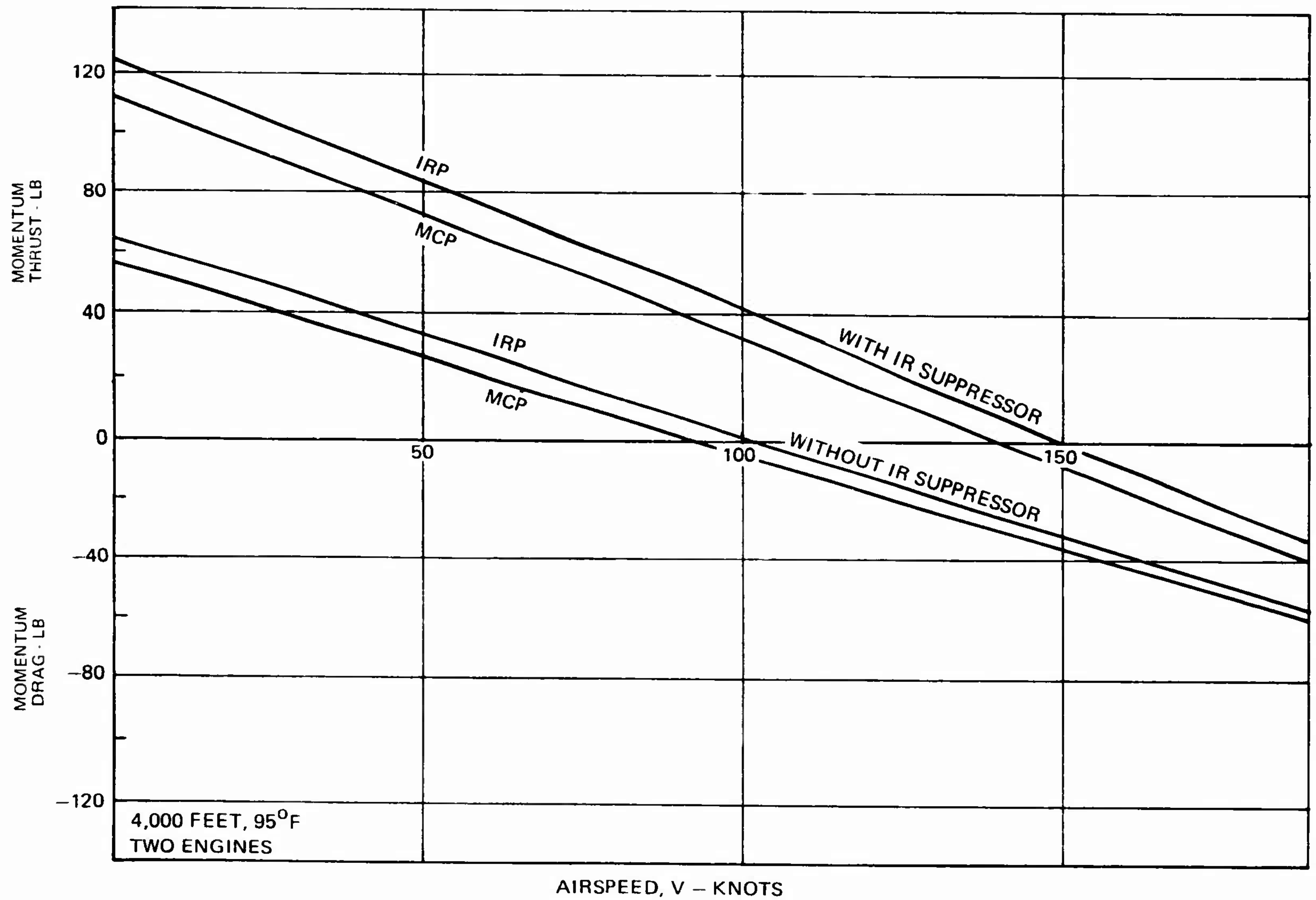


Figure 31. Integrated Airflow Momentum Thrust/Drag Relationship for Baseline Aircraft.

ADVANCED HELICOPTER PRELIMINARY DESIGN

Preliminary designs were conducted for three advanced helicopters listed below with integrated propulsion-driven system installations, selected on the basis of the criteria outlined in CONFIGURATION EVALUATION:

- o Front-drive, horizontal, parallel-mounted engines, ducted fan integrated with tail rotor shaft for cooling flow (Concept b)
- o Front-drive, vertical-mounted engines, direct-drive into main transmission, transmission-driven fan for cooling flow integration (Concept d)
- o Rear-drive, splayed engine mounting, direct-drive into main transmission, ducted fan integrated with tail rotor shaft for cooling flow (Concept f, alternate). The alternate concept was selected because its larger power available improved the vertical climb capability.

As in the case of the baseline aircraft, the preliminary design tasks included a comprehensive structural design of the helicopters, integration of engines and transmissions with the structure, and an accurate determination of the subsystem weight to define total weight empty. Appendix C is a tabulated weight breakdown in accordance with MIL-STD-1374, Part 1.

HORIZONTAL, PARALLEL, FRONT-DRIVE ENGINE (CONCEPT b)

Figure 32 contains a design drawing of the horizontal, front-drive concept. With the exception of the mechanically driven blower to supply the integrated airflows, this concept utilizes the same propulsion-drive system as the baseline. The mixed-flow blower design is integral with the tail rotor drive system and operates at the same speed of 7100 rpm. The blower is located immediately aft of the main transmission, with its exhaust flow ducted without valves or control systems to the plug-type IR suppressor units. Blower operation is continuous and supplies cooling air continually to the suppressor-exhaust system during aircraft operation. Arrows are drawn on Figure 32 to illustrate the cooling air flowpaths which are directed around the accessory gearbox and main transmission, through the transmission oil cooler matrix, into the blower, and into the IR suppressor.

In the final version of this aircraft, the accessory gearboxes are located fore and aft of the main transmission, rather than in front of the transmission as shown in the early design. To provide space for the integrated cooling flow blower, the aft accessory gearbox is located attached to the forward bulkhead of the composite tail-boom structure.

Fuel tankage volume requirements, aircraft structural design, and space requirements for the integrated blower system dictate the split fuel tank arrangement pictured in Figure 32.

Figure 33 is an enlargement of the engine installation in the horizontal, front-drive concept. Arrows indicate the different airflow paths. Illustrated in Figure 33 is the air supplied by the blower that cools the metal surfaces of the suppressor and provides exhaust plume dilution. Arrows indicate the integration of engine exhaust, engine compartment cooling air, and IPS scavenge flow in the "daisy mixer" concept surrounding the exhaust tail pipe of the engine.

Figure 34 is a plot of the net momentum thrust (momentum drag at forward flight speeds) for the horizontal, front-drive concept, including engine and IPS airflow, engine compartment cooling flow, and the blower airflow for IR suppressor hot metal cooling and exhaust plume dilution. The large blower provides sufficient high-pressure air to achieve positive net thrust from the entire system at flight speeds up to 140 knots.

The final weight analyses of the horizontal, front-drive concept resulted in a weight empty of 6166 lb, a 10-lb increase compared with the initial estimate provided in the CONCEPTUAL ANALYSES phase of the study and a 239-lb increase compared to the baseline aircraft. The changes from the initial CONCEPTUAL ANALYSES entailed adjustments in body weight, engine and IR suppressor weight, fuel system weight, and armor. Of the 239-lb increase over the baseline, 215 lb was the IR suppression system. Body weight increased 27 lb and armor 70 lb (the oil cooler matrix was substantially armored in the lower quadrants). The impact of elimination of the IPS blower on engine weight was assessed more carefully, resulting in a 22-lb decrease in weight. Also, the fuel system weighed 36 lb less.

This increase in empty weight resulted in a reduction in the design mission radius to 4.5 NM, approximately 40 NM less than the baseline. The increased accessory power required for the

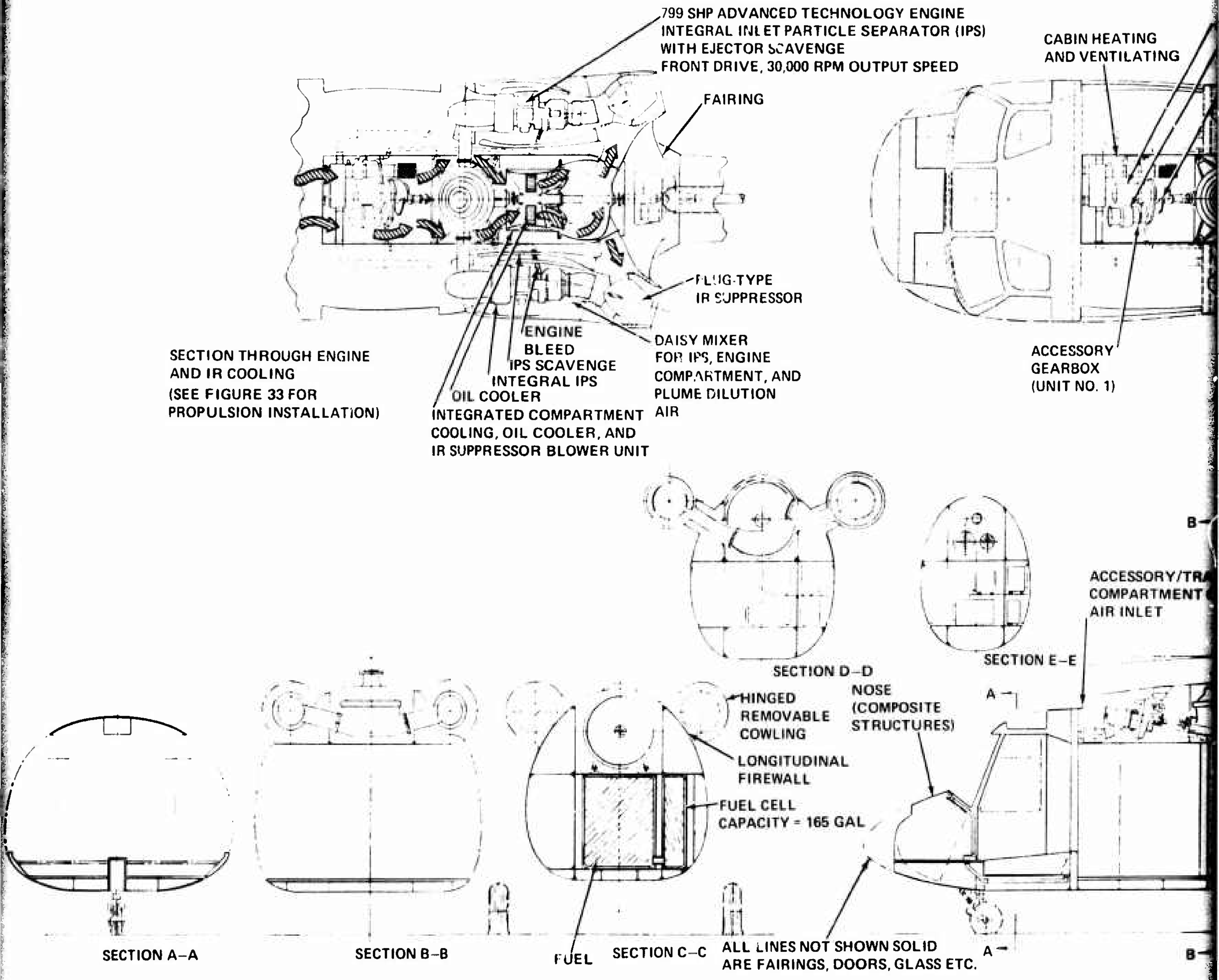
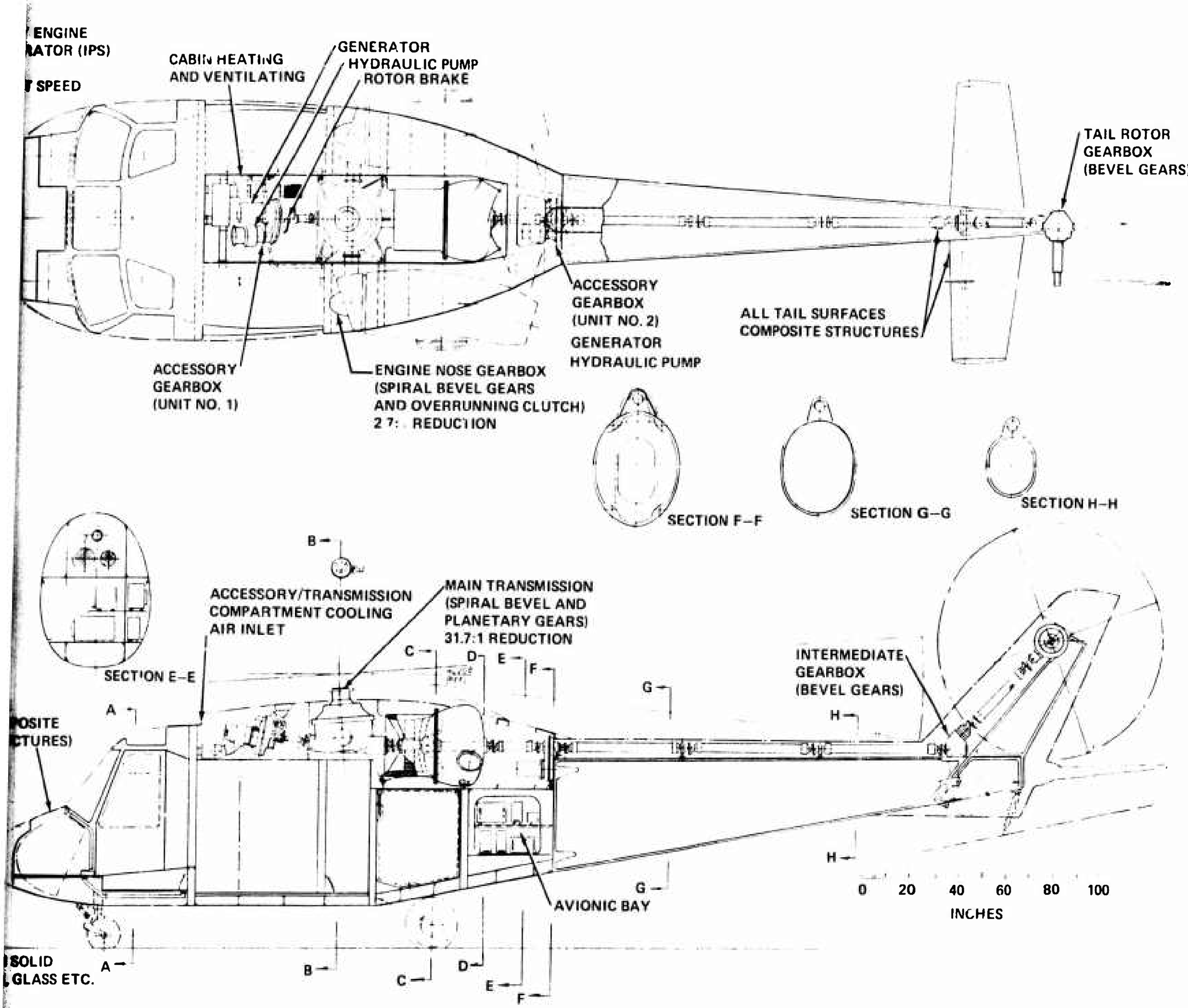


Figure 32. Preliminary Design and Propulsion Installation Drawing of Integrated Propulsion-Drive System, Concept b.



ENGINE
RATOR (IPS)
SPEED
CABIN HEATING
AND VENTILATING
GENERATOR
HYDRAULIC PUMP
ROTOR BRAKE
TAIL ROTOR
GEARBOX
(BEVEL GEARS)
ACCESSORY
GEARBOX
(UNIT NO. 2)
GENERATOR
HYDRAULIC PUMP
ALL TAIL SURFACES
COMPOSITE STRUCTURES
ACCESSORY
GEARBOX
(UNIT NO. 1)
ENGINE NOSE GEARBOX
(SPIRAL BEVEL GEARS
AND OVERRUNNING CLUTCH)
2 7: . REDUCTION
SECTION F–F
SECTION G–G
SECTION H–H
SECTION E–E
ACCESSORY/TRANSMISSION
COMPARTMENT COOLING
AIR INLET
MAIN TRANSMISSION
(SPIRAL BEVEL AND
PLANETARY GEARS)
31.7:1 REDUCTION
INTERMEDIATE
GEARBOX
(BEVEL GEARS)
POSITE
CTURES)
AVIONIC BAY
0 20 40 60 80 100
INCHES
SOLID
GLASS ETC.

ving

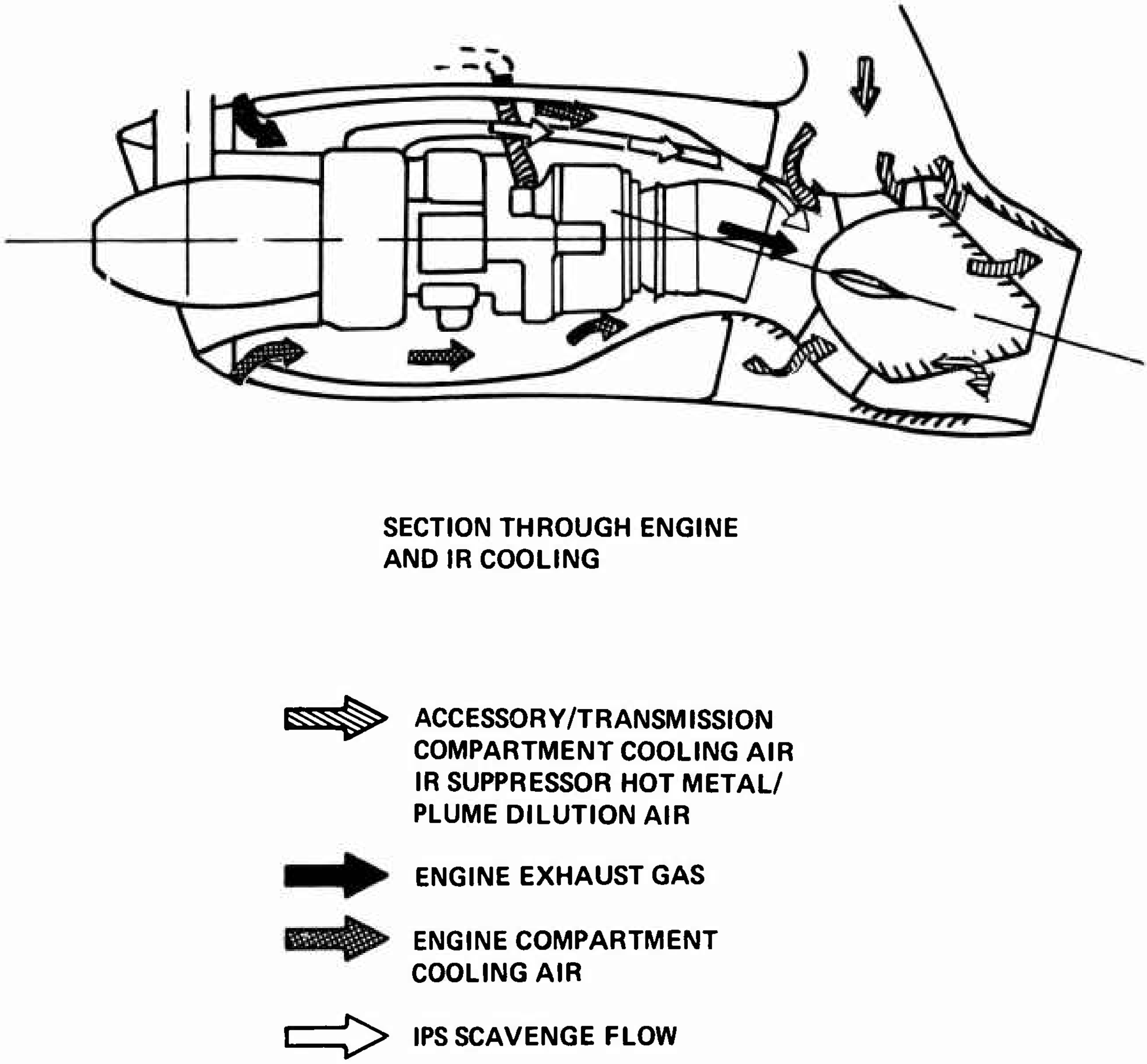


Figure 33. Propulsion Installation Drawing of Concept b.

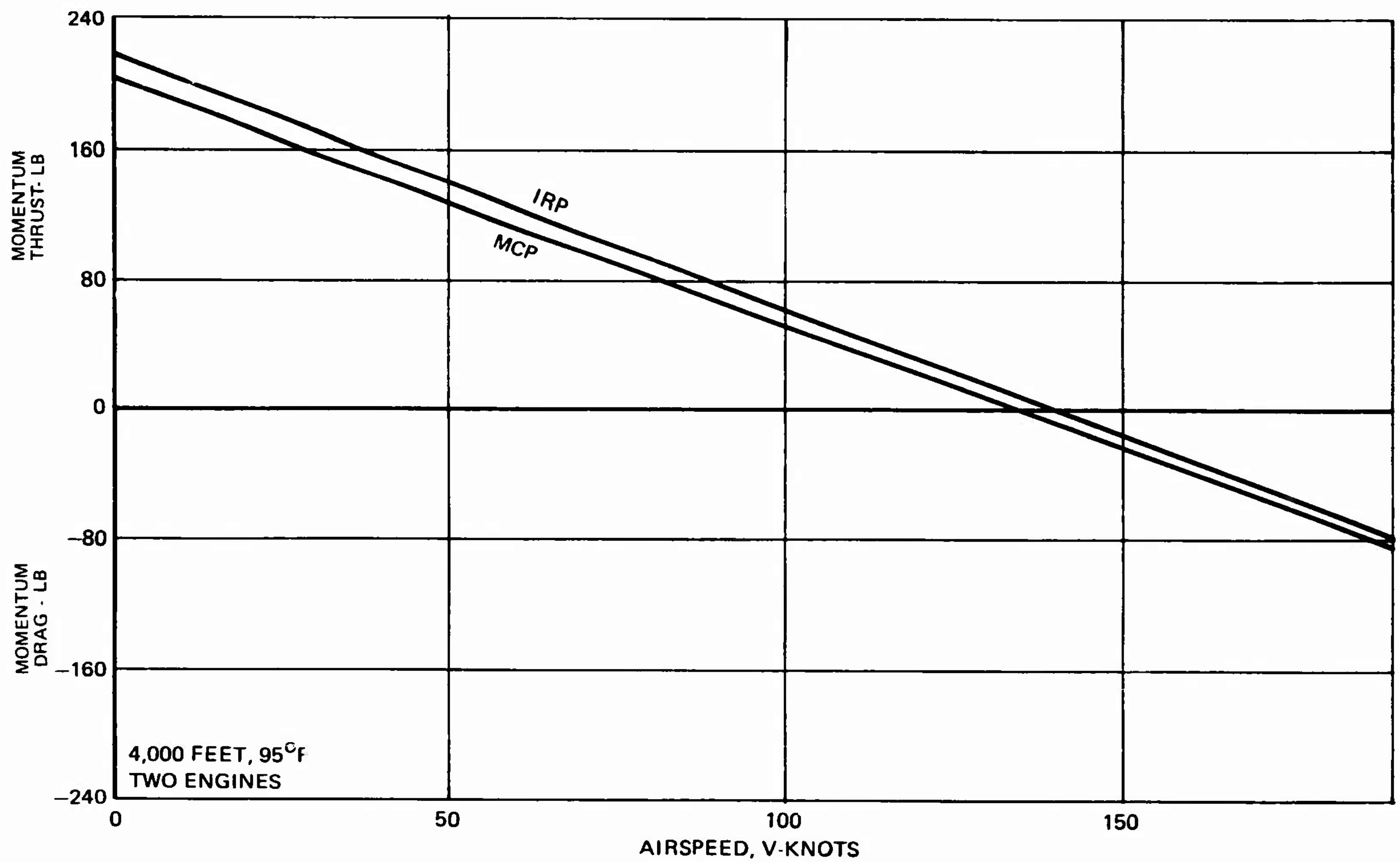


Figure 34. Integrated Airflow Momentum Thrust/Drag Relationship for Concept b.

integrated blower reduced the power available to the rotor, decreasing the vertical climb capability to 130 fpm or 405 fpm less than the baseline.

VERTICAL, FRONT-DRIVE ENGINE (CONCEPT d)

Figure 35 is a three-view inboard drawing of the vertical, front-drive concept. Shown is the propulsion-drive system installation. Greater detail, with some major changes, has been provided in this preliminary design drawing as compared with the previous conceptual design. The lateral arrangement of the vertical engines in the conceptual design was such that the rear bulkhead of the cabin had to be moved forward of the main transmission. The resulting forward location of aircraft cockpit and cabin had an adverse impact on overall length and ease of transportability. A more detailed design study of the main transmission showed that by the appropriate arrangement of the spur gears, the engine centerline could be moved rearward and the outboard location maintained with the addition of an idler, spur gear. The final design of the main transmission is pictured schematically in Figure 36.

A high-speed overriding clutch assembly, indicated in Figure 35, is incorporated as an integral part of the main transmission. Reference 6 provides the design details pertaining to this clutch concept, which has a splined input shaft to accommodate the front output shaft drive of the vertically mounted engines, through appropriate flexible couplings. The size and installation of the overriding clutch and the arrangement of the main transmission do not impact the aerodynamic performance of the plenum-bellmouth engine inlet.

The spur gear arrangement for the main transmission is compromised to the extent necessary to accommodate the flight control swashplate actuator as shown in the plan view of Figure 36. The outboard location of the vertical engines also requires the use of idler gears to accommodate the offset distance. The buttline beam main structure is compromised in design to permit installation of the larger transmission on the aircraft upper deck and within the buttline beam structure.

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(6) P. Lynwander, A. G. Meyer, and S. Chachakis, SPRING OVERRIDING AIRCRAFT CLUTCH, AVCO Lycoming Division, Stratford, Connecticut; USAAMRDL Technical Report 73-17, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, May 1973, AD 766309.

Main transmission design impacted the drive systems for the accessory gearboxes, the tail rotor drive, and the IR suppressor blower. A separate spur-gear drive was incorporated integrally into the rear of the main transmission (Figure 36), with an external bevel gear drive attached and driven by this spur gear through a short drive shaft. Through appropriate bevel gears, drive shafts, and flexible couplings, this external bevel gear provides the drives to the forward accessory gearbox and rotor brake, the integral drive for the aft accessory gearbox and tail rotor drive and the IR suppressor blower. The forward AGB and rotor brake is driven through a separate short drive shaft from the external bevel gear, passing underneath the main transmission.

In the vertical, front-drive concept, the large IR suppressor blower is located vertically between the engines. High-pressure discharge air is ducted and processed through a large plenum to a jumbo-slot type suppressor design. Engine exhaust is deflected upward to prevent line-of-sight hot metal radiation and to provide personnel protection from the hot exhaust gases during ground handling.

Net momentum thrust for Concept d is plotted in Figure 37, and includes engine and IPS airflow, engine compartment cooling flow, and the blower airflow for IR suppressor hot metal cooling and exhaust plume dilution. The large turning angle of the integrated exhaust flow results in net ram drag for the system at flight speeds greater than 100 knots.

The final weight analysis of Concept d indicated a weight empty of 6232 lb, 68 lb heavier than the initial estimate provided in CONCEPTUAL ANALYSES. The significant changes in subsystem weight estimates were as follows:

Body weight	=	+38 lb
Engine section	=	+31 lb
Engine	=	-22 lb
IR suppression	=	-53 lb
Starting/fuel systems	=	-58 lb
Transmission	=	+109 lb
Armor	=	+24 lb

Compared to the baseline aircraft, the weight empty increase is 305 lb, including the following major changes:

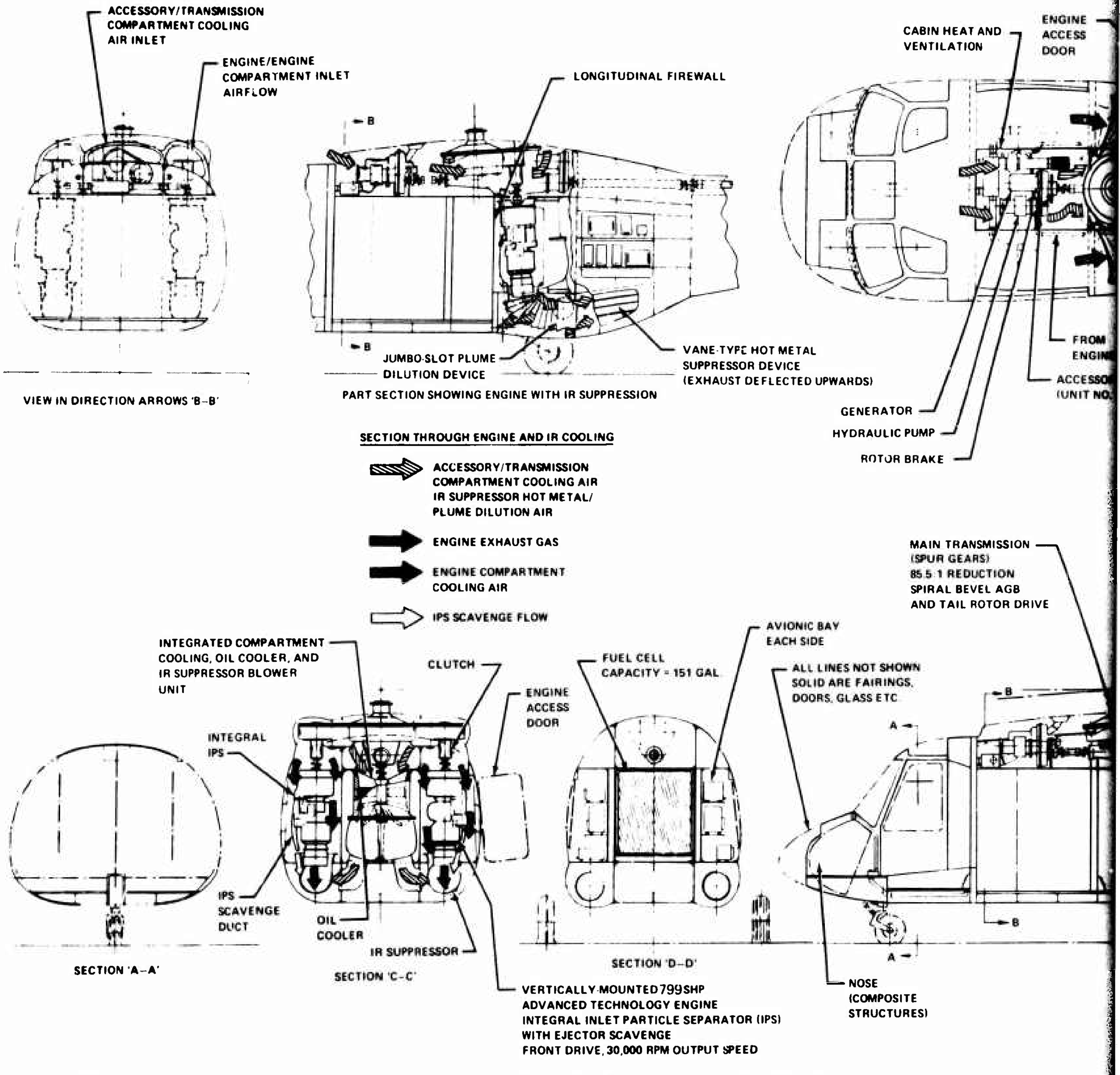
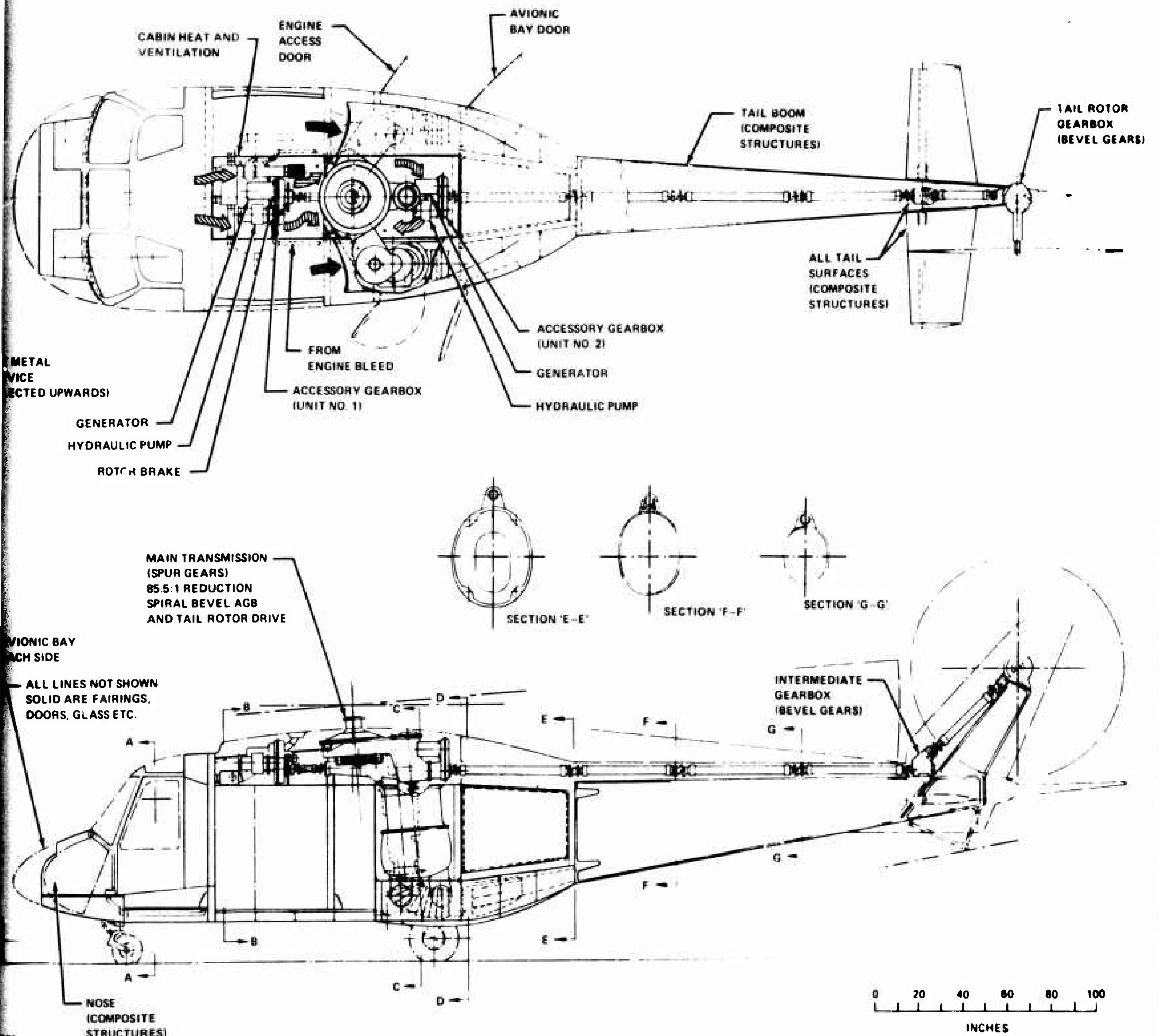
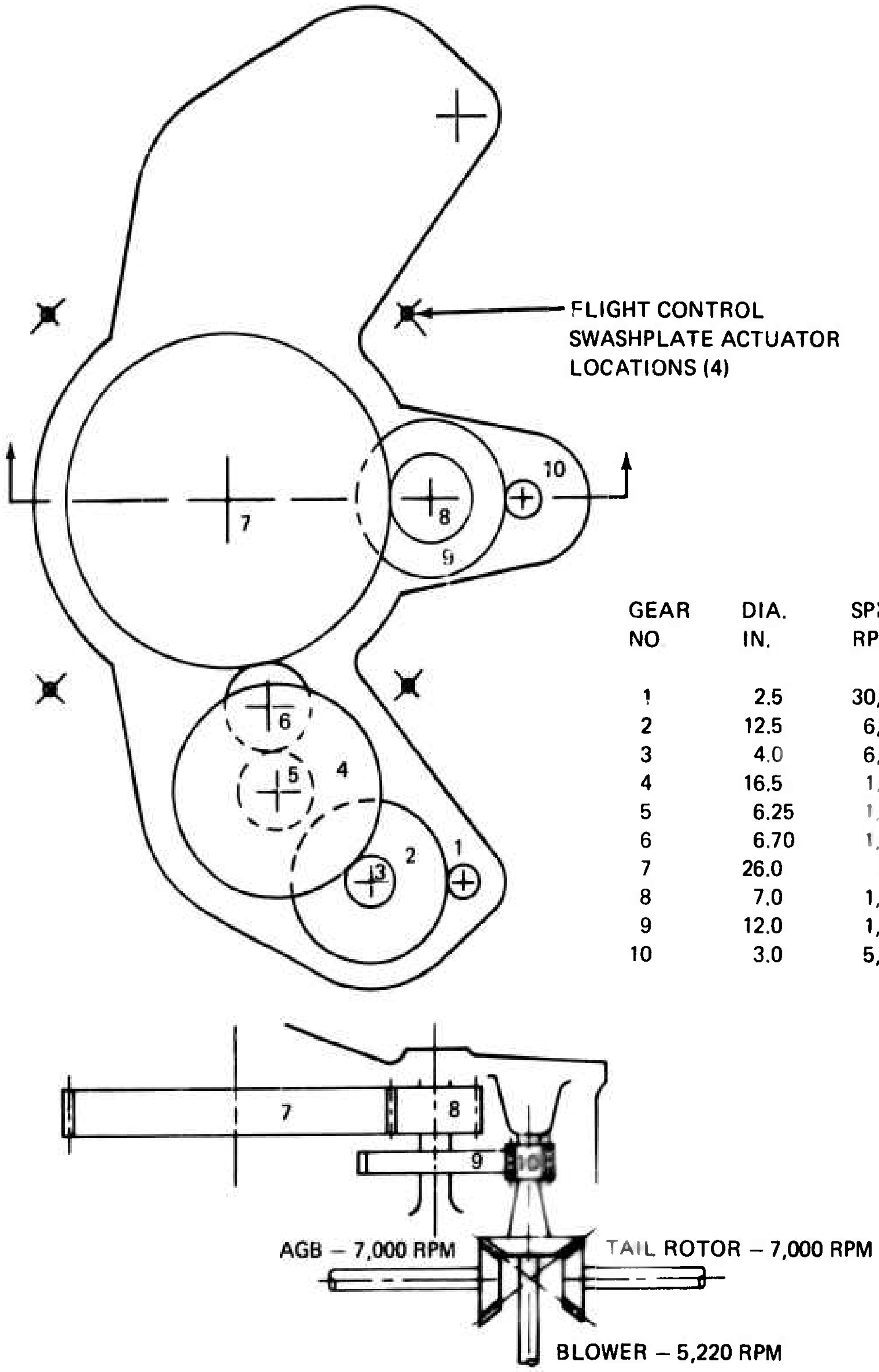


Figure 35. Preliminary Design and Propulsion Installation Drawing of Integrated Propulsion-Drive System, Concept d.


CABIN HEAT AND VENTILATION
ENGINE ACCESS DOOR
AVIONIC BAY DOOR
TAIL BOOM (COMPOSITE STRUCTURES)
TAIL ROTOR GEARBOX (BEVEL GEARS)
ALL TAIL SURFACES (COMPOSITE STRUCTURES)
ACCESSORY GEARBOX (UNIT NO. 2)
GENERATOR
HYDRAULIC PUMP
FROM ENGINE BLEED
ACCESSORY GEARBOX (UNIT NO. 1)
METAL
VICE
ECTED UPWARDS)
GENERATOR
HYDRAULIC PUMP
ROTOR BRAKE
MAIN TRANSMISSION (SPUR GEARS) 85.5:1 REDUCTION SPIRAL BEVEL AGB AND TAIL ROTOR DRIVE
SECTION 'E-E'
SECTION 'F-F'
SECTION 'G-G'
VIONIC BAY
ACH SIDE
ALL LINES NOT SHOWN SOLID ARE FAIRINGS, DOORS, GLASS ETC.
INTERMEDIATE GEARBOX (BEVEL GEARS)
NOSE (COMPOSITE STRUCTURES)
0 20 40 60 80 100
INCHES

wing



GEAR NO	DIA. IN.	SPEED RPM
1	2.5	30,000
2	12.5	6,000
3	4.0	6,000
4	16.5	1,455
5	6.25	1,455
6	6.70	1,360
7	26.0	351
8	7.0	1,305
9	12.0	1,305
10	3.0	5,220

Figure 36. Drive System Gear Reductions and Shaft Speeds for Concept d.

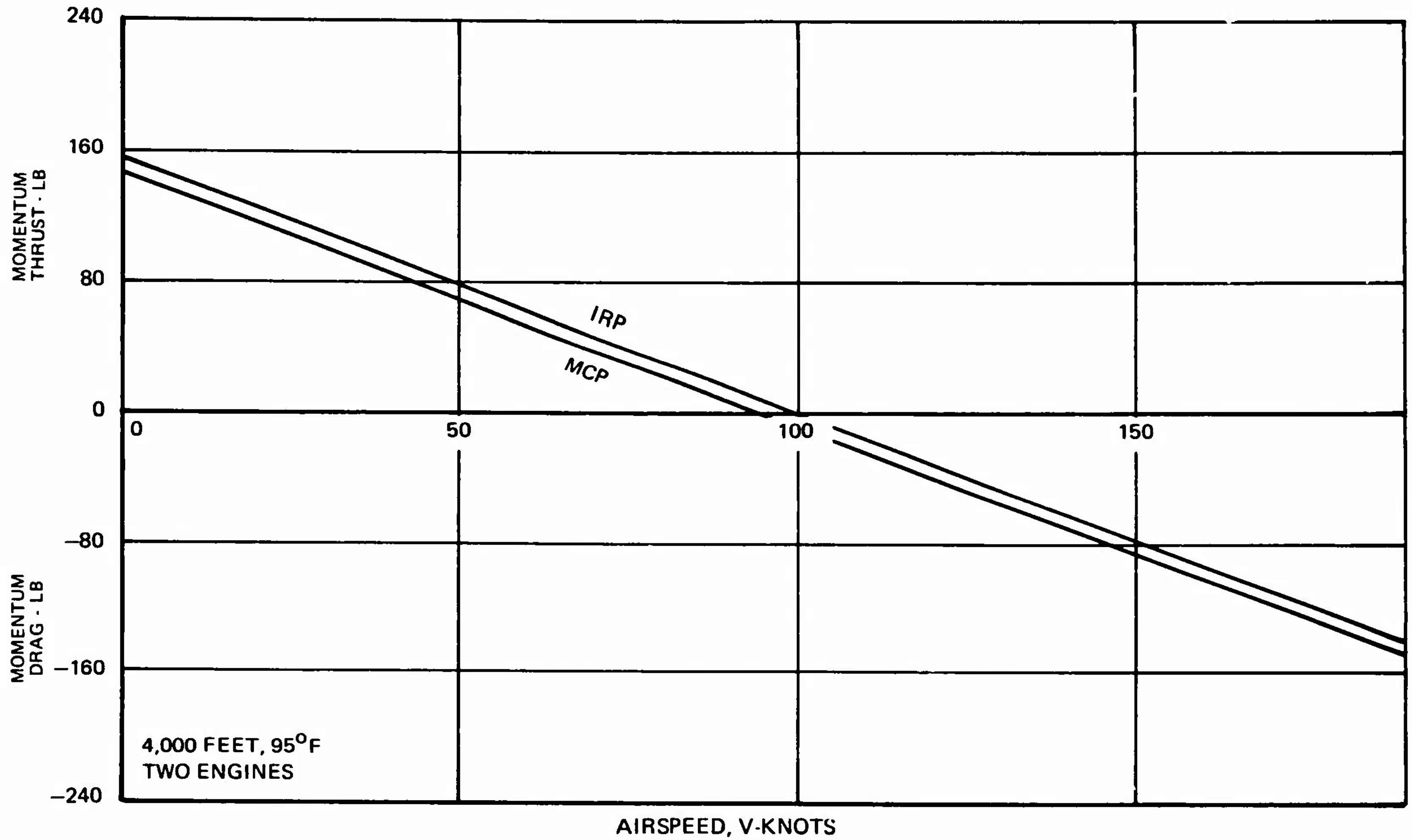


Figure 37. Integrated Airflow Momentum Thrust/Drag Relationships for Concept d.

Body weight	=	+48 lb
Engine section (mounts/firewalls)	=	+55 lb
Engine	=	-22 lb
IR suppression system	=	+145 lb
Starting/fuel systems	=	-55 lb
Transmission	=	+118 lb

Preliminary performance studies show that the primary mission radius, for an aircraft DGW of 8500 pounds, is 47 NM less than the baseline. The increased installation losses and accessory power requirements severely impact the vertical rate-of-climb capability of this concept, resulting in an 83-fpm VRC (453 fpm less than the baseline).

HORIZONTAL, DIRECT REAR-DRIVE ENGINE (CONCEPT f)

Illustrated in Figure 38 are the structural design and the integration of the horizontal, direct rear-drive concept. The splayed engine mounting arrangement of this concept has a rear, direct drive through an overrunning spring-clutch integral with a conventional bevel-planetary gear transmission. A ducted blower integrated with the tail rotor shaft provides air for hot metal cooling and exhaust plume dilution. The jumbo-slot duct IR suppressor concept also utilizes rotor downwash to accomplish part of the exhaust plume dilution. The blower charges the vane-type hot metal suppressor and internal jumbo-slot duct with 5.45 lb/sec of cooling air. The external jumbo-slot duct provides an additional 3.45 lb/sec of cooling air, approximately 30 percent of the mixed flow, by ejector action. Since the dilution airflow added in this manner is a small percentage of the total flow and the density of the mixed flow is changing, the impact on the cross-section area of the slotted duct is small.

The major subsystem changes in the horizontal direct rear-drive concept adopted during the preliminary design phase were:

- o Aft accessory gearbox relocated to the main forward bulkhead of the tail boom but integral with the tail rotor drive shaft, aft of the centrifugal blower.

- o Removal of the plug-type IR system in favor of a vane-type arrangement followed by the jumbo-slot section (using rotor downwash).

- o Use of an innovative removable overrunning clutch design integral with the main transmission (Figure 39).

- o Position of the centrifugal blower reversed to provide for a more effective IR suppressor system.

The power turbine high speed (30,000 rpm) output engine shaft drives directly into the main transmission through a special integral overriding clutch. The main rotor transmission for the horizontal, direct rear-drive aircraft is similar in overall envelope to the baseline aircraft main transmission. However, it differs in that an additional planetary stage is added, and the engine nose gearbox eliminated, permitting the direct engine drive. This transmission utilizes an engine pinion gear drive through a large spiral bevel collector gear as the first stage reduction, followed by two planetary stages, as shown schematically in Figure 40. The separate integral oil cooler system is identical to the system used for the baseline aircraft.

Fuel tankage volume requirements, aircraft structural design, and space requirements for the integrated blower and avionics bays dictate the split fuel tank arrangement pictured in the drawing.

The final weight analysis of Concept f resulted in a weight empty of 6216 lb, 24 lb lighter than the initial estimate provided in CONCEPTUAL ANALYSES, including the following significant changes in predicted subsystem weights:

Body weight	=	+49 lb
Engine section	=	+40 lb
Engine	=	-22 lb
IR suppression system	=	-177 lb
Starting/fuel system	=	-55 lb
Transmission	=	+88 lb

The weight empty was 289 lb heavier than the baseline aircraft due to the following major changes in subsystem weights:

Body weight	=	+26 lb
Engine section	=	+69 lb
Engine	=	-22 lb
Airframe-mounted IPS	=	+20 lb
IR suppression system	=	+184 lb
Starting/fuel system	=	-52 lb
Transmissions	=	+48 lb
Armor	=	+17 lb

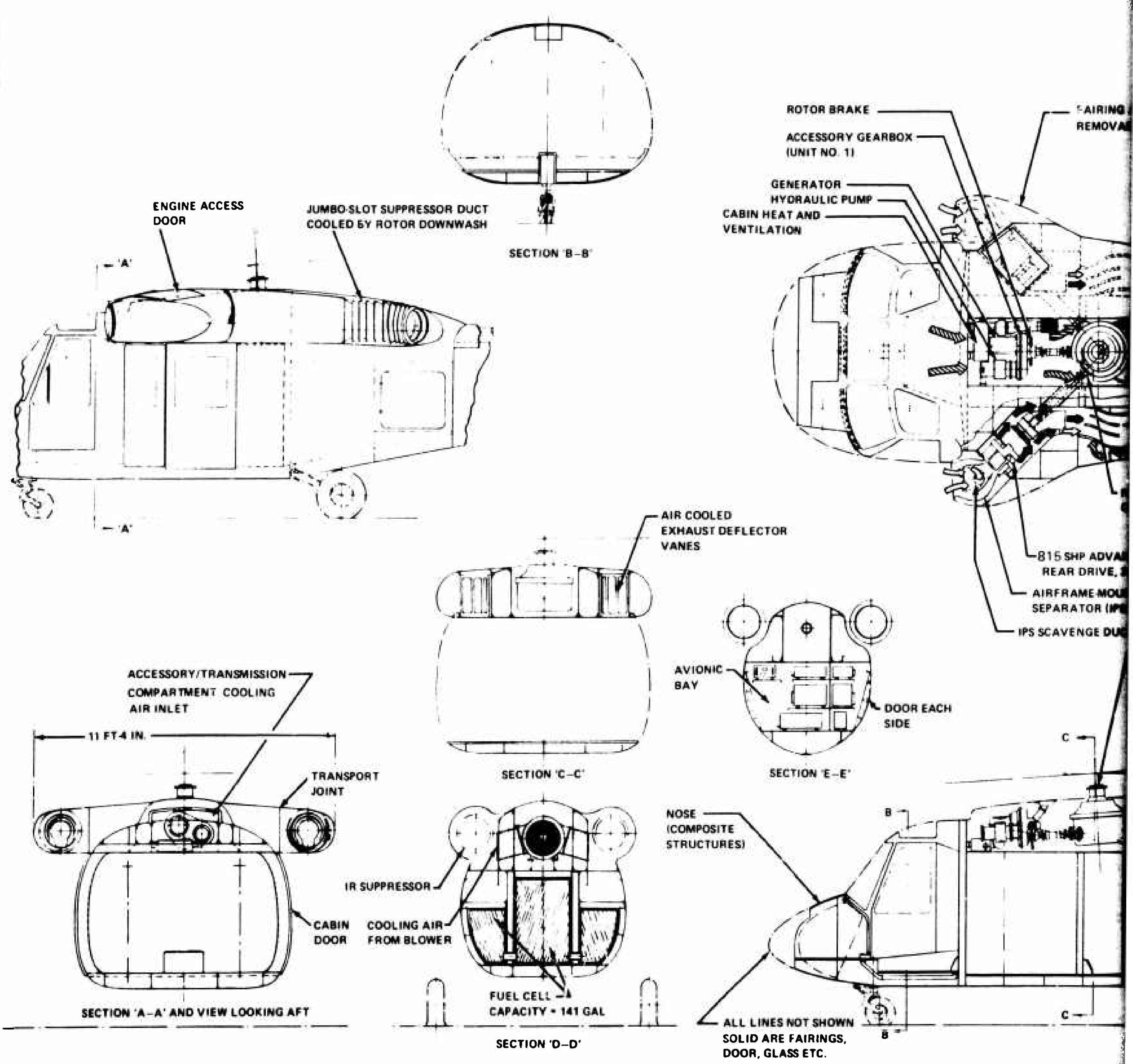
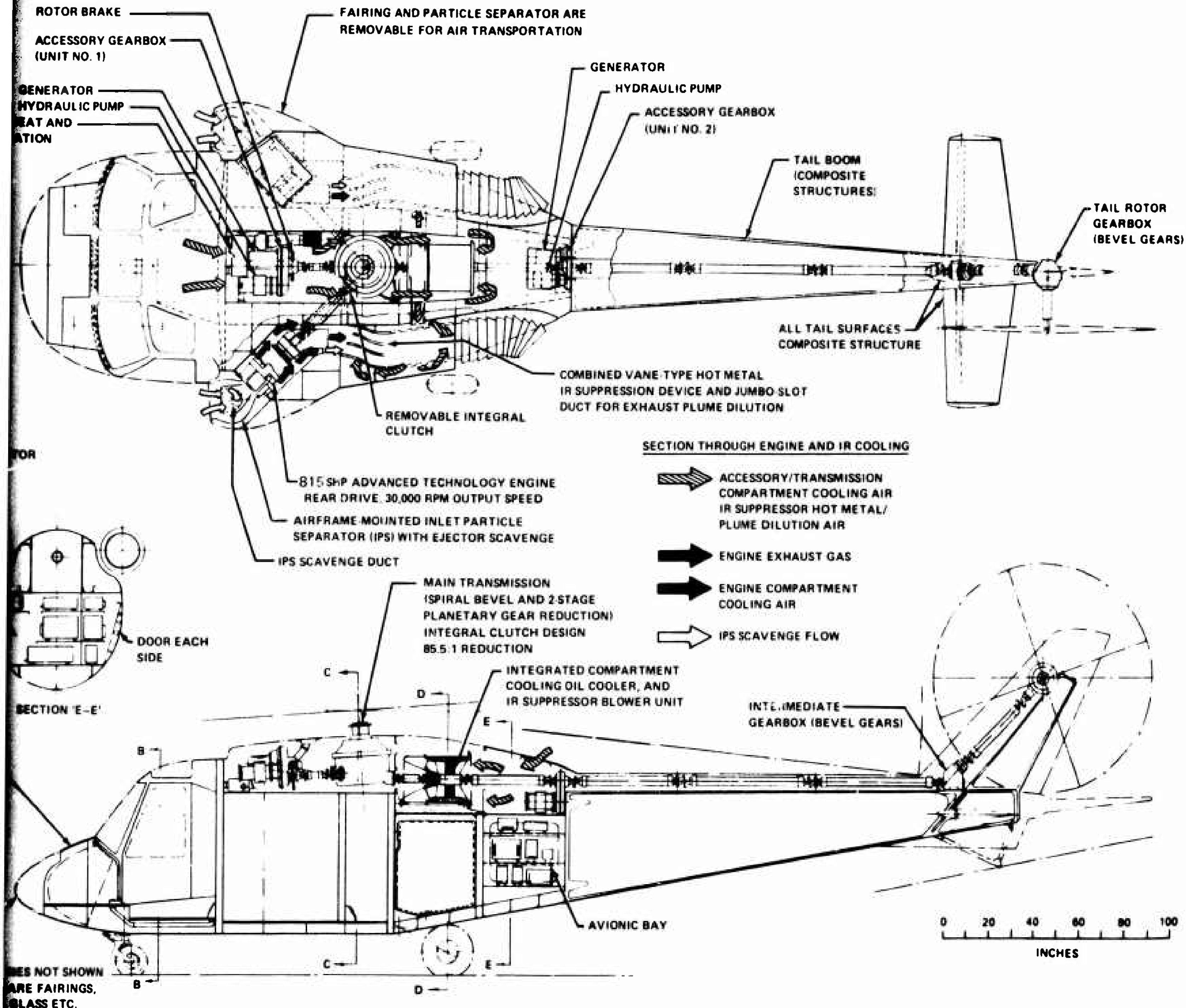
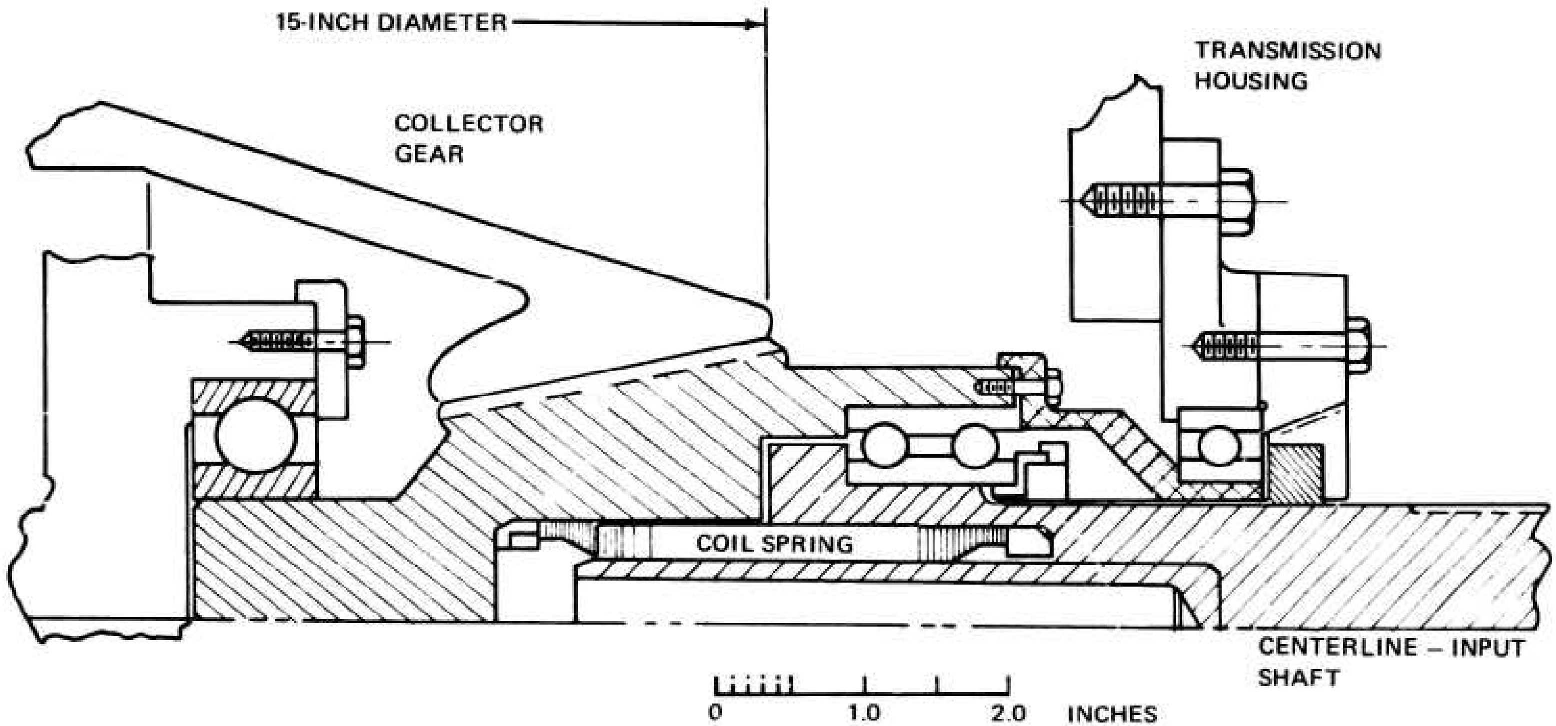


Figure 38. Preliminary Design and Propulsion Installation Drawing of Integrated Propulsion-Drive System, Concept f.



ROTOR BRAKE
ACCESSORY GEARBOX (UNIT NO. 1)
GENERATOR
HYDRAULIC PUMP
FAIRING AND PARTICLE SEPARATOR ARE REMOVABLE FOR AIR TRANSPORTATION
GENERATOR
HYDRAULIC PUMP
ACCESSORY GEARBOX (UNIT NO. 2)
TAIL BOOM (COMPOSITE STRUCTURES)
TAIL ROTOR GEARBOX (BEVEL GEARS)
ALL TAIL SURFACES COMPOSITE STRUCTURE
COMBINED VANE-TYPE HOT METAL IR SUPPRESSION DEVICE AND JUMBO SLOT DUCT FOR EXHAUST PLUME DILUTION
REMOVABLE INTEGRAL CLUTCH
SECTION THROUGH ENGINE AND IR COOLING
815 SHP ADVANCED TECHNOLOGY ENGINE REAR DRIVE. 30,000 RPM OUTPUT SPEED
AIRFRAME MOUNTED INLET PARTICLE SEPARATOR (IPS) WITH EJECTOR SCAVENGE
IPS SCAVENGE DUCT
ACCESSORY/TRANSMISSION COMPARTMENT COOLING AIR IR SUPPRESSOR HOT METAL/ PLUME DILUTION AIR
ENGINE EXHAUST GAS
ENGINE COMPARTMENT COOLING AIR
IPS SCAVENGE FLOW
DOOR EACH SIDE
SECTION 'E-E'
MAIN TRANSMISSION (SPIRAL BEVEL AND 2-STAGE PLANETARY GEAR REDUCTION) INTEGRAL CLUTCH DESIGN 85.5:1 REDUCTION
INTEGRATED COMPARTMENT COOLING OIL COOLER, AND IR SUPPRESSOR BLOWER UNIT
INTERMEDIATE GEARBOX (BEVEL GEARS)
AVIONIC BAY
0 20 40 60 80 100
INCHES
B
C
D
E
ARE FAIRINGS, GLASS ETC.

Drawing
f.



REFERENCE: DESIGN B, PAGE 15 OF REFERENCE 6.

Figure 39. Advanced Spring Overriding Clutch Design for Concept f.

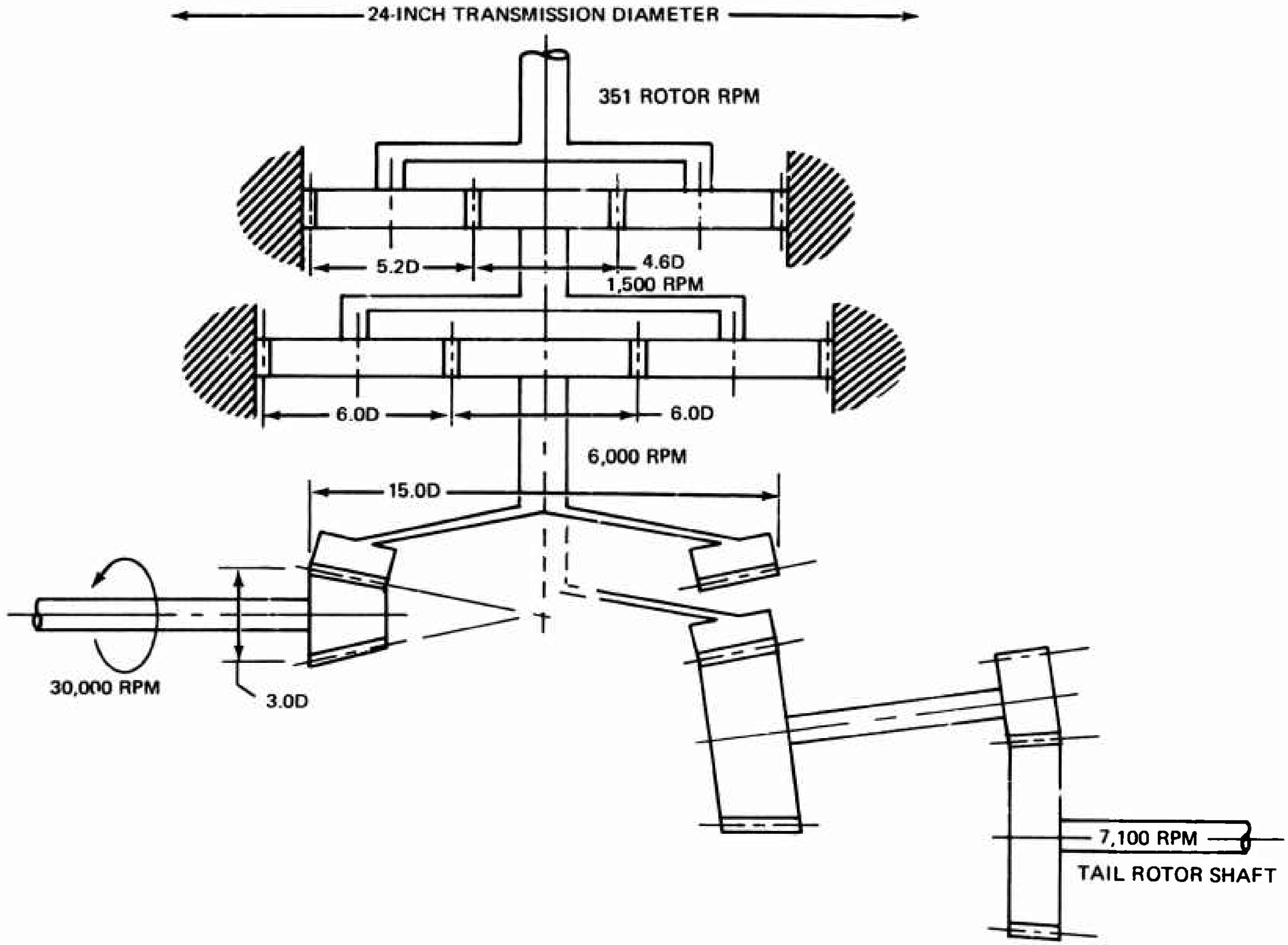


Figure 40. Drive System Gear Reductions and Shaft Speeds for Concept f.

As a consequence of the weight empty increase, the design primary mission radius is 45 NM less than the baseline aircraft.

The jumbo-slot cooling technique using rotor downwash minimizes the IR suppressor blower size and power requirements, which were initially estimated as 45 shp. Revised calculations during the preliminary design phase indicated that the blower must provide more of the plume dilution airflow than originally intended, as well as the hot metal cooling airflow, to stimulate the required ejector action in the exhaust duct. The resulting blower power increased to 60 shp. The accessory power requirements associated with the integrated blower system still were substantially less than the accessory power requirements of the other advanced aircraft, so the vertical rate-of-climb capability improved to 280 fpm, 256 fpm less than the baseline aircraft.

Concept f, like Concept d, has a large turning angle of the integrated IR suppressor exhaust flow which results in the same momentum thrust/drag relationship as a function of flight speed.

Alternate Direct-Drive Transmission Design

An alternate transmission based on an advanced concept proposed for Boeing Vertol's CH-47 aft transmission was applied to the final horizontal, direct rear-drive concept. A schematic of the gear arrangement, which is similar to the basic transmission, is shown in Figure 41. The alternate transmission design features a reduced envelope size, a completely integrated oil reservoir and cooling system, and a fully integrated flight control actuator system. A representative sketch of the advanced concept is shown in Figure 42. The alternate, advanced-concept transmission impacts the upper deck and buttline beam structural design, which results in a significant reduction in transmission and vehicle structural weight. The level of technology employed in this transmission is substantially advanced beyond that utilized in the baseline design. The resulting vehicle design cannot be compared directly to the other aircraft, which incorporate state-of-the-art drive system technology.

The advanced-technology main transmission consists of a spiral-bevel stage; a four-spur-gear planetary stage; a six-spur-gear, split-carrier, planetary stage; and an integral oil

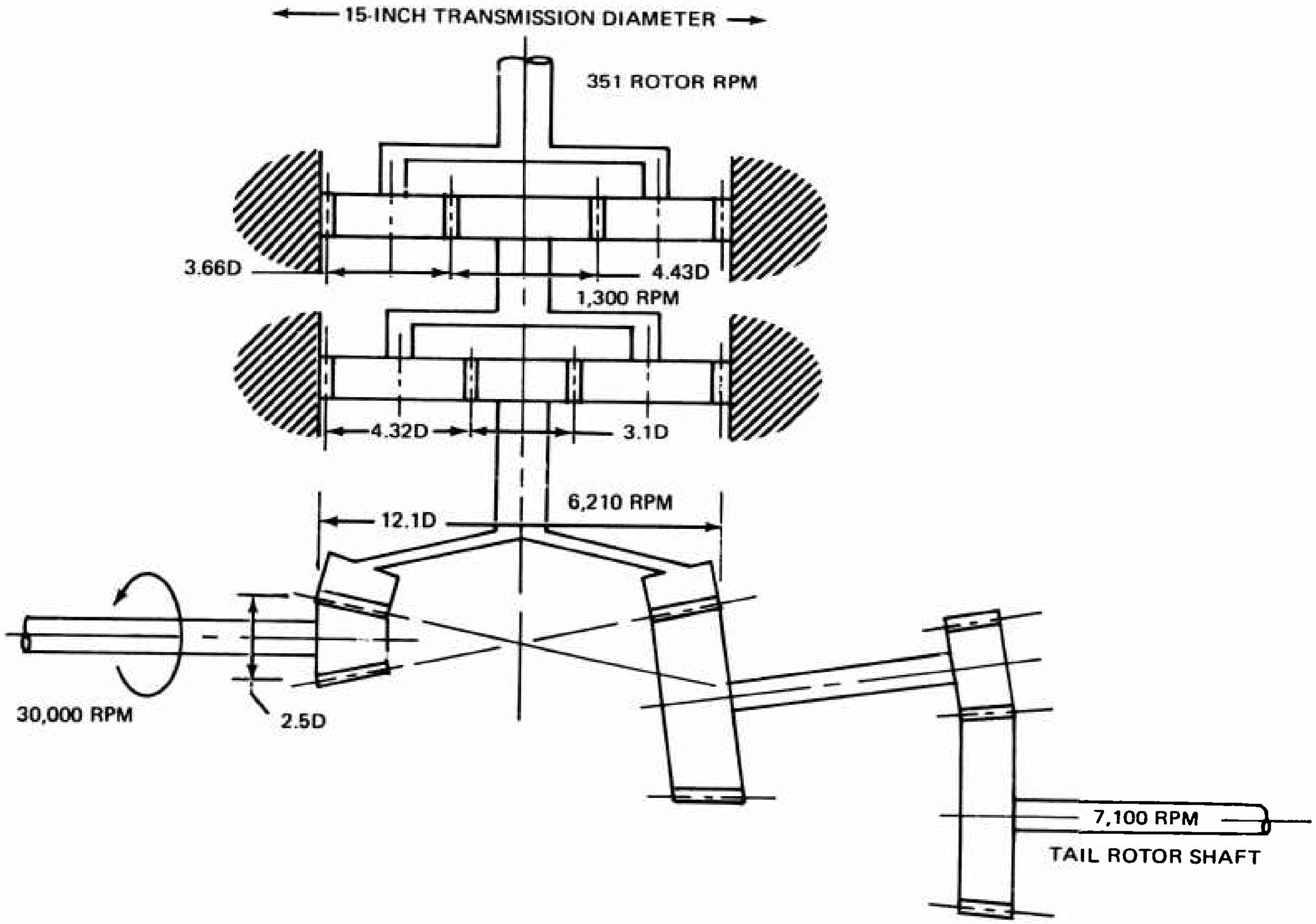


Figure 41. Advanced-Concept Transmission Schematic for Concept f.

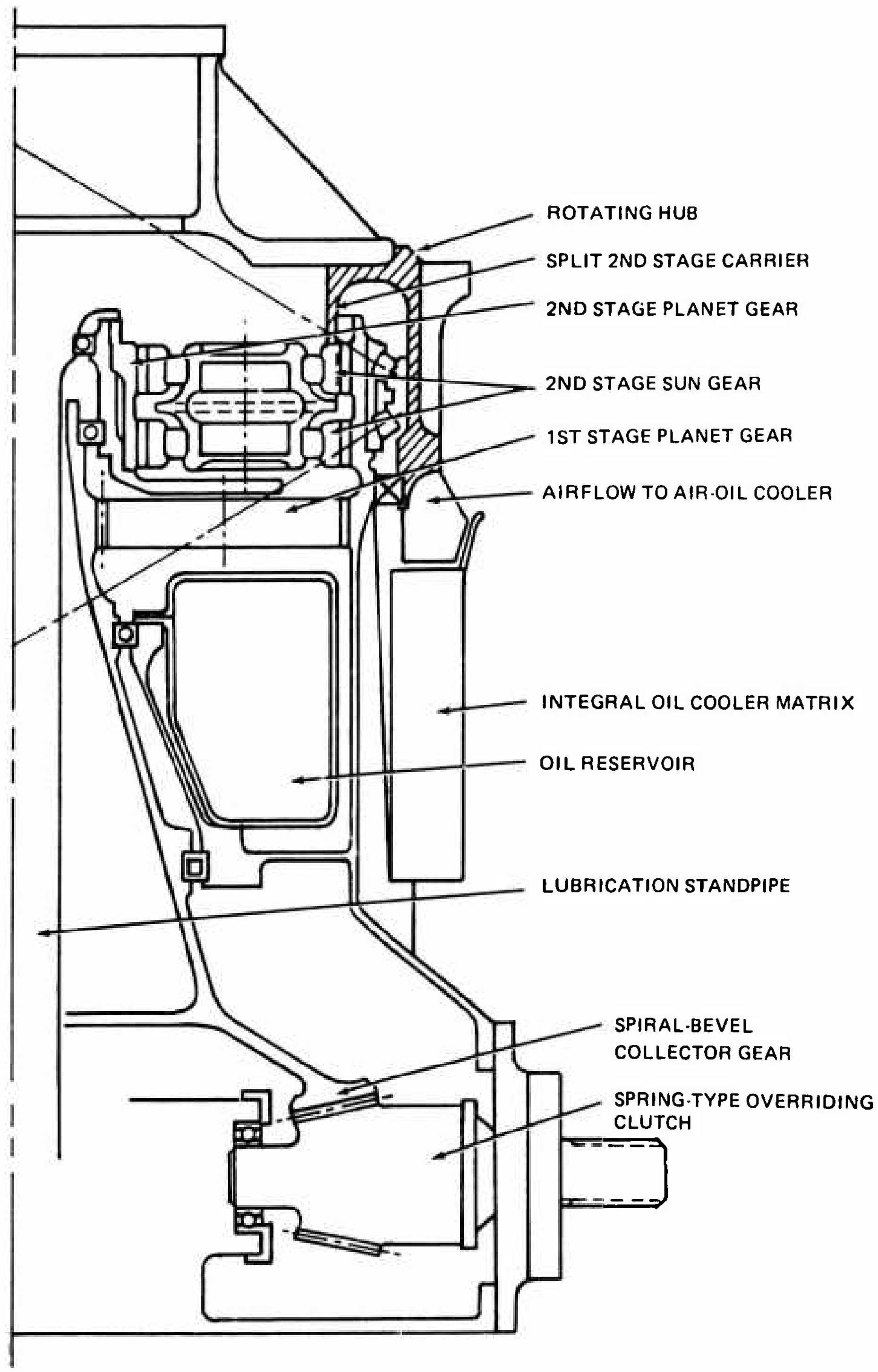


Figure 42. Advanced-Concept Transmission Design for Concept f.

cooling system. The advanced-concept transmissions have not been optimized. It would be desirable for the advanced concept to reduce the 1st stage bevel gear ratio and the 3rd stage planetary gear ratio, or perhaps increase the ratios in both planetary stages. It is expected that this advanced transmission would be refined and available for use by 1980. The horizontal, direct rear-drive concept was designed to accept this smaller and more compact main transmission with the vehicle configuration modified to take advantage of its reduced size and weight.

The sketch of the advanced concept transmission, Figure 42, shows the special overriding clutch assembly integrated with the main transmission housing. The special clutch configuration is based on the design and dimensions of Design B in Reference 6.

A weight trend curve was established for the advanced-concept main transmissions based on the torque requirements, and resulted in a weight savings of 70 lb for the advanced-concept transmission in the horizontal, direct rear-drive configuration.

The smaller, more compact main transmission permits the upper-deck, buttline beam structure to be reduced in width, thus permitting the engine installation to be moved inboard as shown in Figure 43. The IR suppression system is altered, eliminating the large plenum and external "jumbo-slot" configuration in favor of a more conventional plug-type, ram-ejector IR suppression system. The IR centrifugal blower airflow and power requirements remain the same, but the integrated oil cooler/blower design is reduced in length with the elimination of the oil-cooler system.

The incorporation of an advanced-technology main transmission not only reduces the size of the upper-deck, buttline beam structural assembly, but also impacts the vehicle minimum weight by eliminating large duct work associated with the IR suppression system. In addition, with the inboard relocation of the engines and the use of the plug-type IR suppressors, the weight of the engine nacelles and sponsons is decreased. The net result is a decrease in weight of 114 lb, or a total weight empty of 6102 lb, 175 lb heavier than the baseline.

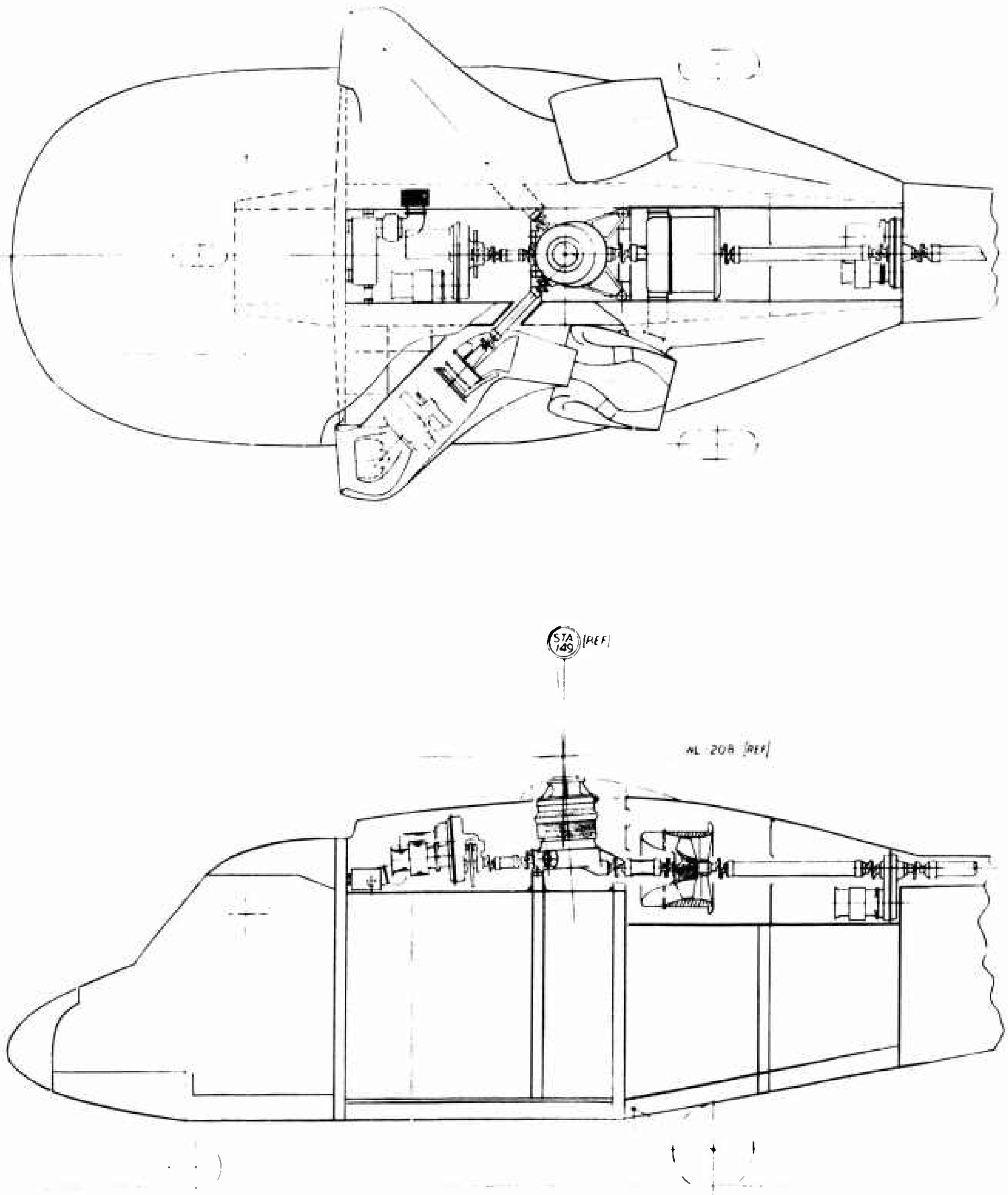
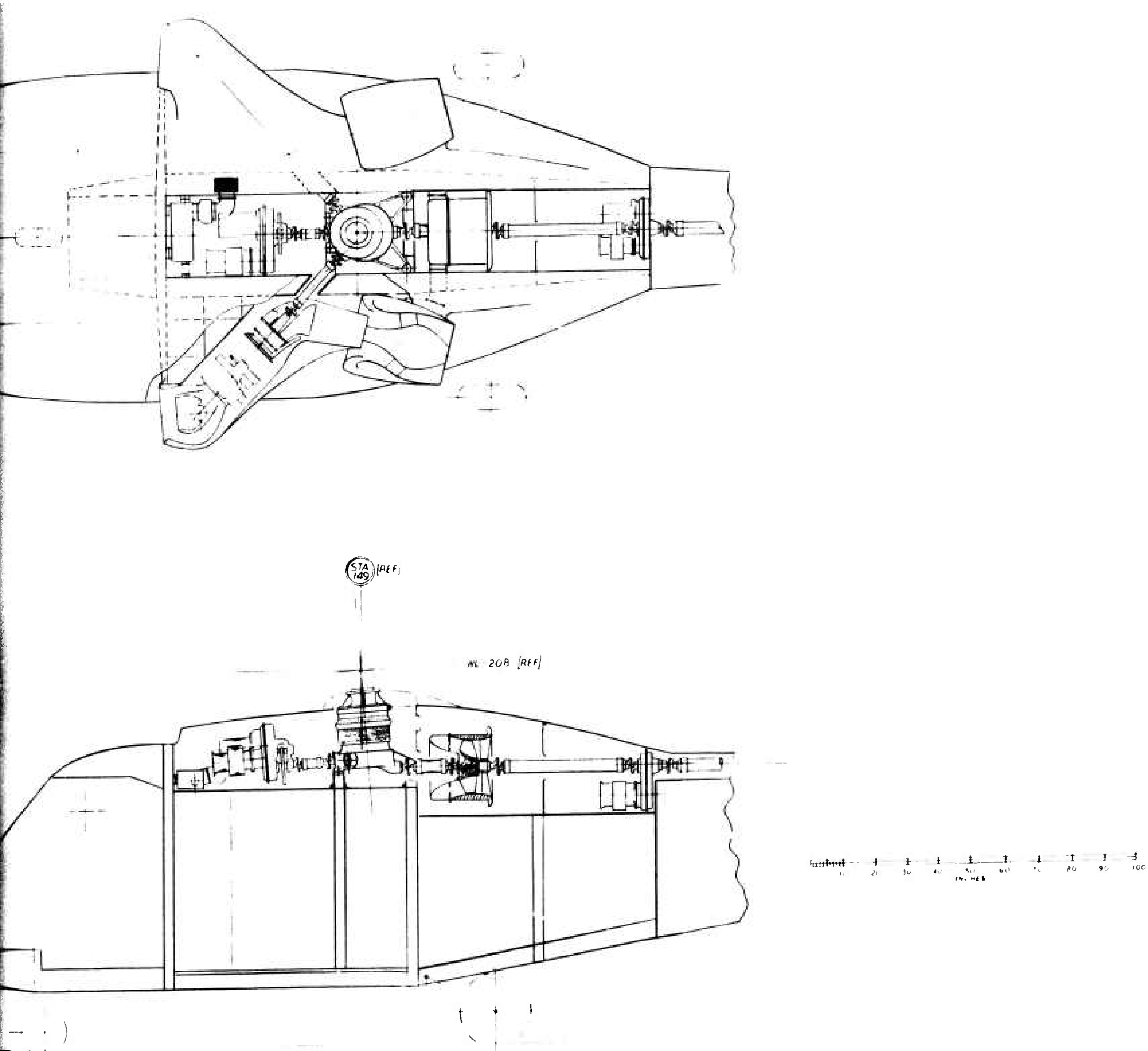


Figure 43. Propulsion Installation Drawing of Concept f
With Advanced-Concept Transmission.



n Installation Drawing of Concept f
nced-Concept Transmission.

DESIGN ANALYSIS

During this phase of the program, comparative analyses of the preliminary designs were conducted, including cooling airflow requirements and drag effects. A detailed breakdown of aircraft power requirements and associated performance capabilities was obtained for each aircraft. In addition, a weight empty breakdown was developed consistent with MIL-STD-1374, Part 1. Analyses were conducted for the baseline aircraft, both with and without a current IR suppressor, and for the three advanced aircraft with integrated propulsion-drive system concepts, plus the direct, rear-drive concept with the advanced-technology main transmission introduced previously. The level of technology utilized in the advanced transmission is superior to the state-of-the-art drive systems in the other aircraft, preventing direct comparisons of weight and performance parameters. Areas of technical risk for each of the concepts were defined and assessed.

Table 10 describes the blower and IR suppressor of each of the propulsion-drive system concepts. Because of its lower weight and lower accessory power requirements relative to the advanced integration concepts, the current IR suppressor on the baseline aircraft is deemed most desirable from the standpoint of aircraft performance. However, the current suppressor provides substantially less protection against the IR missile threat, as illustrated graphically in Figure 4. The SYSTEM REQUIREMENTS section dictated suppressed IR signatures substantially less than those obtainable with the current suppressor. The advanced concepts were necessary to achieve the desired improvement in IR suppression, and provided greatly reduced complexity in terms of numbers of subsystems and components.

Also included in this section of the report are comparative weight and performance characteristics developed for "rubberized" versions of each of the aircraft, sized to meet the same mission and climb requirements.

COMPARATIVE ANALYSES

Integrated cooling flow requirements for the advanced concepts and for the current IR suppressor design on the baseline aircraft are defined in Appendix A. The momentum thrust (or drag) corresponding to the integrated flows was presented previously as a function of flight speed.

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TABLE 10. IR SUPPRESSOR AND BLOWER DESIGN DATA

Concept	Integrated Cooling Airflows (per Engine)				IR Suppression System				
	Primary Blower	Primary (Blower) Airflow lb/sec	Secondary (Ejector) Airflow lb/sec	Power Requirement shp	Type	Hot Metal Cooling Airflow lb/sec	Hot Metal Cooling Temperature °F	Exhaust Plume Dilution Airflow lb/sec	Exhaust Plume Dilution Temperature °F
a Baseline					None				
a' Baseline + Current IR Suppressor	Hydraulic Blower	1.00	0.90	8.0	Plug-Type Suppressor	1.00	275.	0.90	642.
b Horizontal Front-Drive Engines	Mechanical Blower	8.90		45.0	Plug-Type Suppressor	3.00	200.	5.90	400.
d Vertical Front-Drive Engines	Mechanical Blower	8.90		45.0	Jumbo-slot and Vane-Type Suppressor	3.00	200.	5.90	400.
f Horizontal Direct-Drive Engines	Mechanical Blower	5.45	3.45	30 0	Jumbo-slot Duct	5.45	200.	3.45	400.

In these paragraphs, comparative performance and weight data generated for the selected concepts and sensitivity trends for key system characteristics are summarized.

Aircraft Drag

The results of the final iteration of aircraft drag terms by subsystem and component are listed in Table 11, including the momentum ram drag contributions.

Power Requirements

The power requirements for the final design concepts are tabulated in Table 12.

As noted, the accessory power requirements are 25 shp throughout. The blower power penalty for the current IR suppressor actually included 8 shp accessory power and 4 shp performance loss attributed to back pressure on the engine. The blower power penalty for the horizontal, direct-drive concept (f) was revised upward from the initial estimate of 45 shp to 60 shp, as a result of the detail design requirements of the IR suppressor concept.

The integral IPS and scavenge blower of the baseline engines resulted in a power available of 1104 shp, while the integral IPS system of the horizontal, front-drive and direct-drive concepts without the scavenge blower resulted in a power available of 1113 shp (95-percent IRP at 4000 feet, 95°F). The integral IPS without a scavenge blower in the vertical, front-drive concept (d), with the power penalties associated with the plenum inlet, resulted in a power available of 1104 shp. Transmission losses of 2.78 percent were deducted from the useable power to determine the climb power available to the main and tail rotor.

Figure 44 graphically illustrates the excess hover power available and the climb power available for each of the concepts.

Aircraft Performance and Sensitivity Studies

Performance and weight data are presented for the baseline aircraft, with no IR suppressor, with the current IR suppressor design, and for advanced aircraft with propulsion integration concepts, including the direct, rear-drive concept with

TABLE 11. COMPONENT DRAG BUILDUP COMPARISONS FOR SELECTED CONCEPTS

Concept	a Baseline	a' Baseline + Current IR Suppressor	b Horizontal Front-Drive Engines	d Vertical Front-Drive Engines	f Horizontal Direct-Drive Engines	f' Advanced-Concept Transmission
Fuselage	1.49	1.49	1.49	1.54	1.45	1.45
Main Rotor Pylon	.18	.24	.24	.31	.18	.18
Engine Nacelles	.41	.43	.45	.-	.95	.66
Inlets	-	-	-	.15	-	-
Slotted Exhaust Duct	-	-	-	-	1.80	1.80
Integrated Airflow Momentum*	.45	0	.15	1.00	1.00	1.00
Vertical Tail	.27	.27	.27	.27	.27	.27
Horizontal Tail	.23	.23	.23	.23	.23	.23
Tail Rotor Assy	.86	.86	.86	.86	.86	.86
T.R. to Fin Interference	.06	.06	.06	.06	.06	.06
Hub	3.57	3.57	3.57	3.57	3.57	3.57
Landing Gear	3.31	3.31	3.31	3.31	3.31	3.31
Protuberances	.91	.91	.91	.91	.91	.91
Trim Drab	.34	.34	.34	.34	.34	.34
Total	12.08	11.71	11.88	12.55	14.93	14.64

* 4000 feet, 95° F, 140 Knots

TABLE 12. VERTICAL CLIMB POWER COMPARISONS FOR SELECTED CONCEPTS

Concept	a Baseline	a' Baseline + Current IR Suppressor	b Horizontal Front-Drive Engines	d Vertical Front-Drive Engines	f Horizontal Direct-Drive Engines
	Shaft Horsepower				
Engine Power Available*	1104	1104	1113	1104	1113
Integrated Blower Power	0	24	90	90	60
Accessory Power	25	25	25	25	25
Transmission Loss	30	29	28	28	29
Rotor Power Available	1049	1026	970	961	999
Main Rotor Hover Power	861	861	861	861	861
Main Rotor Climb Power	90	70	22	14	47
Tail Rotor Climb Power	98	95	87	86	91
Main-Tail Rotor Power Req'd	1049	1026	970	961	999
Vertical Rate of Climb - fpm	536	417	131	83	280

* 95 percent IRP, 4000 feet, 95° F

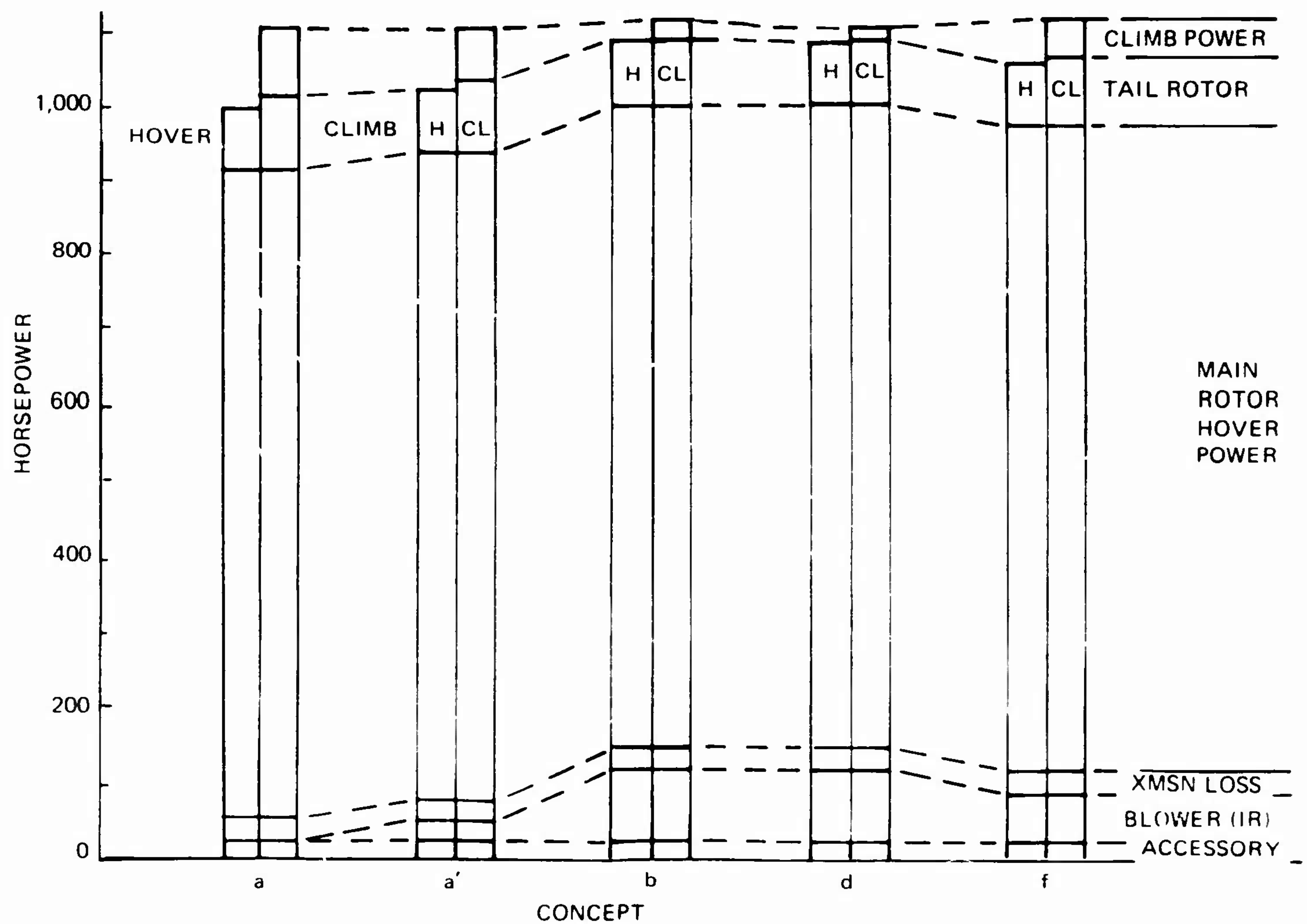

Figure 44. Power Distribution Comparison for Hover and Climb.

an advanced-technology main transmission. Table 13 lists the overall aircraft performance parameters of principal interest.

Data illustrating the vertical rate-of-climb capability and the mission radius for the primary design mission and for the alternate "Radius Mission" are contained in the table and graphically compared in Figures 45 and 46.

Sensitivity factors developed for the baseline aircraft and three advanced helicopters include:

- Sensitivity of primary design mission radius to aircraft drag, accessory power, and structural weight (plotted in Figure 47).
- Sensitivity of forward speed at engine maximum continuous power, sea level/59°F, to aircraft drag, accessory power, and structural weight (plotted in Figure 48).
- Sensitivity of vertical rate of climb to accessory power (plotted in Figure 49).

Figure 47 illustrates that, for constant takeoff gross weight, mission radius is dependent on structural weight, which impacts directly on the weight of fuel. Accessory power has a lesser impact on radius, which is virtually insensitive to drag - 15-percent change in drag results in only a few miles difference in radius. Conversely, the effect of drag on airspeed is illustrated in Figure 48. The sensitivity of vertical rate of climb to power requirements is noted in Figure 49.

Weight Empty Breakdown

A weight empty breakdown per MIL-STD-1374, Part 1, is provided for the study helicopter configuration in Appendix C. Subsystem weights are summarized graphically in Figure 50.

TECHNICAL RISK ASSESSMENT

The system requirements for the study effectively limited the comparative technical risk to an evaluation of the integrated cooling IR suppression systems of the various aircraft. However, some comments should be made concerning technical risk inherent in the different engine configurations, specifically front versus rear drive.

TABLE 13. PERFORMANCE SUMMARY COMPARISONS FOR SELECTED CONCEPTS

Concept	a Baseline	a' Baseline + Current IR Suppressor	b Horizontal Front-Drive Engines	d Vertical Rear-Drive Engines	f Horizontal Direct-Drive Engines	f' Advanced-Concept Transmission
Takeoff Gross Weight - lb	8500	8500	8500	8500	8500	8500
Payload - lb	960	960	960	960	960	960
Fixed Useful Load - lb	506	506	506	506	506	506
Weight Empty - lb	5927	6071	6166	6232	6216	6102
Mission Fuel Available - lb	1107	963	868	802	818	932
Mission Radius						
Primary Mission - NM	43	22	4.5	-4.3	-2	+13
Radius Mission - NM	149	125	108	97	99	116
Vertical Climb Capability -fpm (95 Percent IRP at 4000 Feet, 95°F)	536	417	131	83	280	280

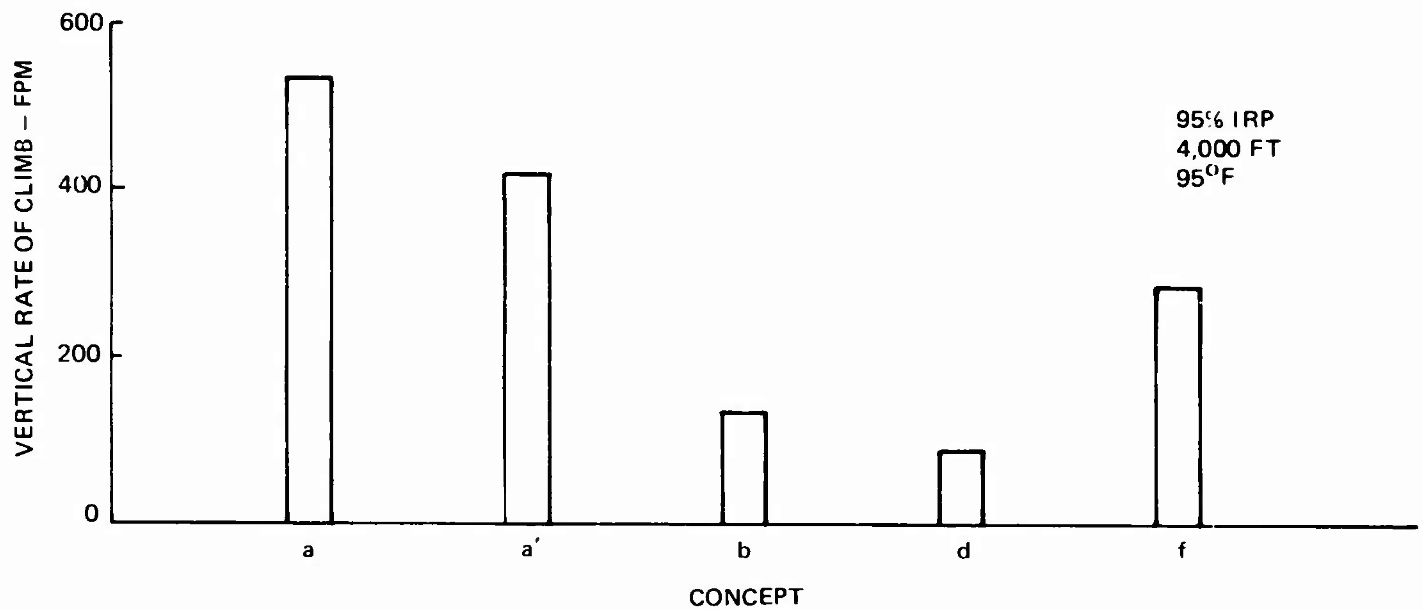

Figure 45. Vertical Climb Performance Comparison.

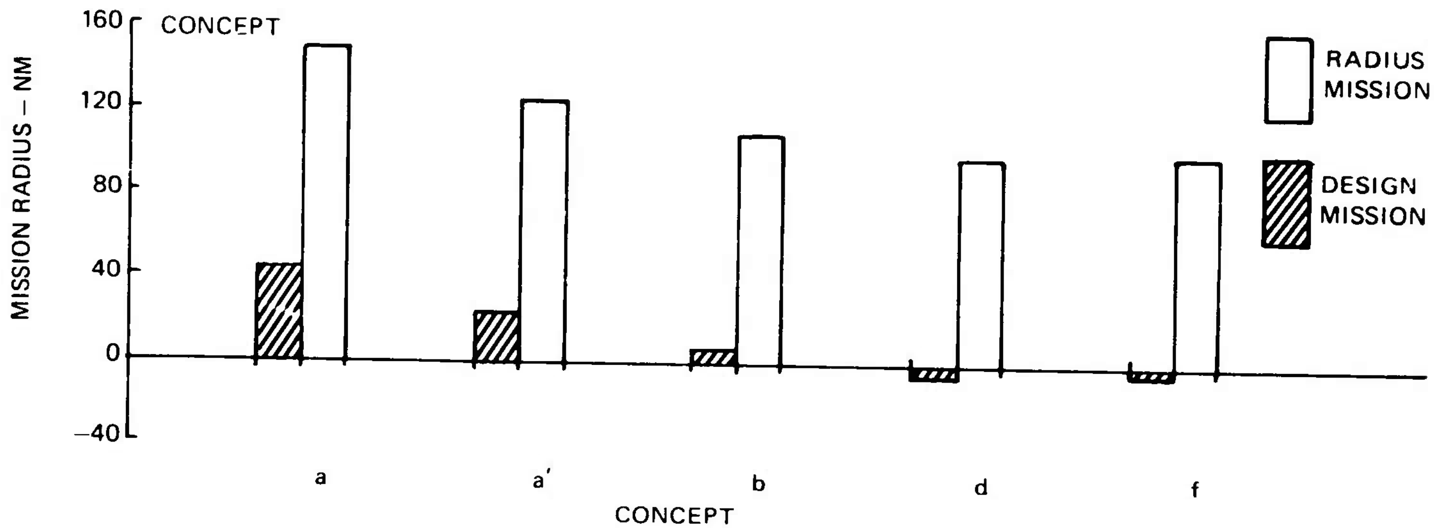

Figure 46. Comparison of Mission Radius for Design Mission and Alternative "Radius Mission".

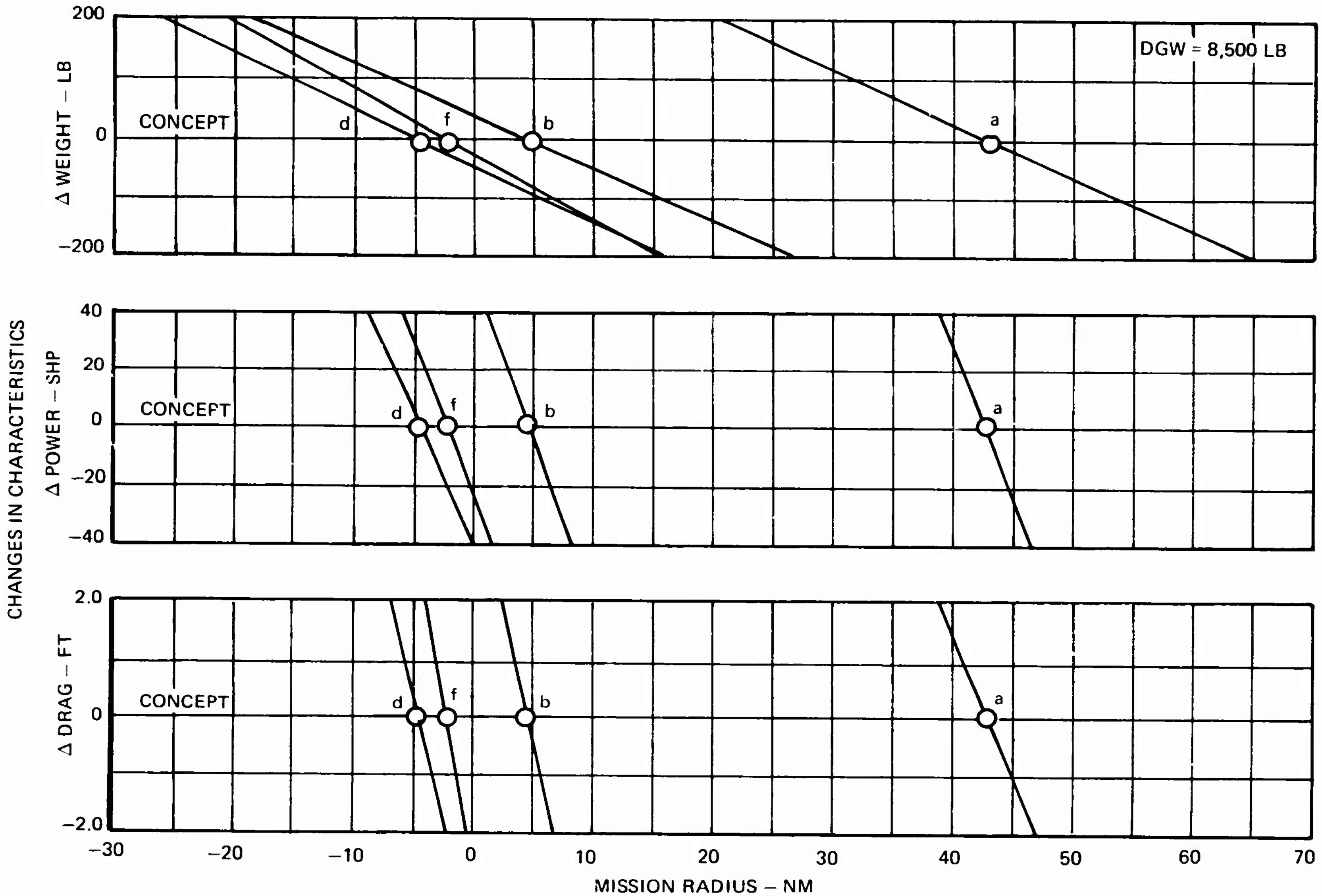

Figure 47. Mission Radius Sensitivity to Drag, Accessory Power, and Structural Weight.

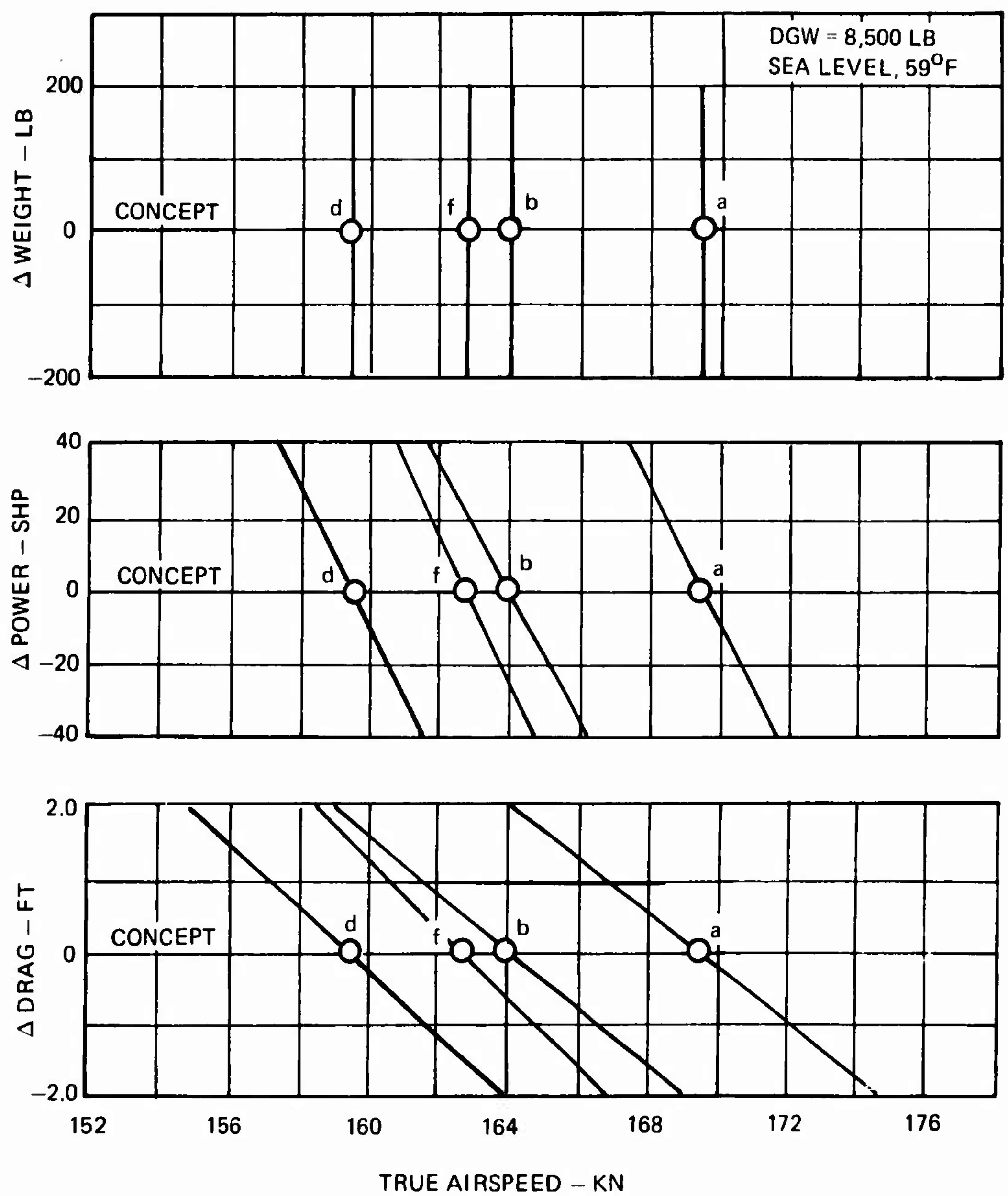

Figure 48. MCP Flight Speed Sensitivity to Drag, Accessory Power, and Structural Weight.

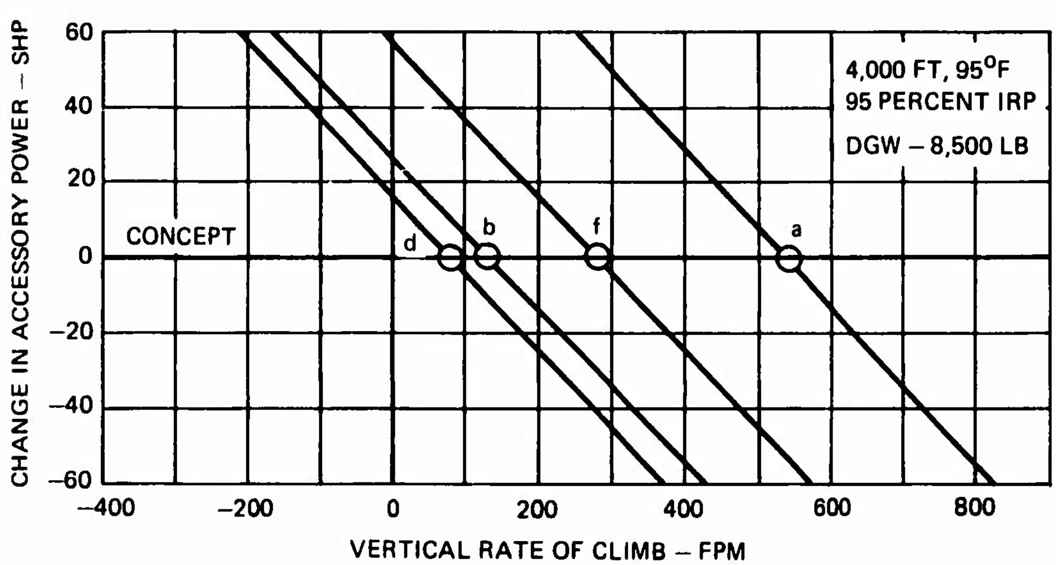

Figure 49. Vertical Rate-of-Climb Sensitivity to Accessory Power.

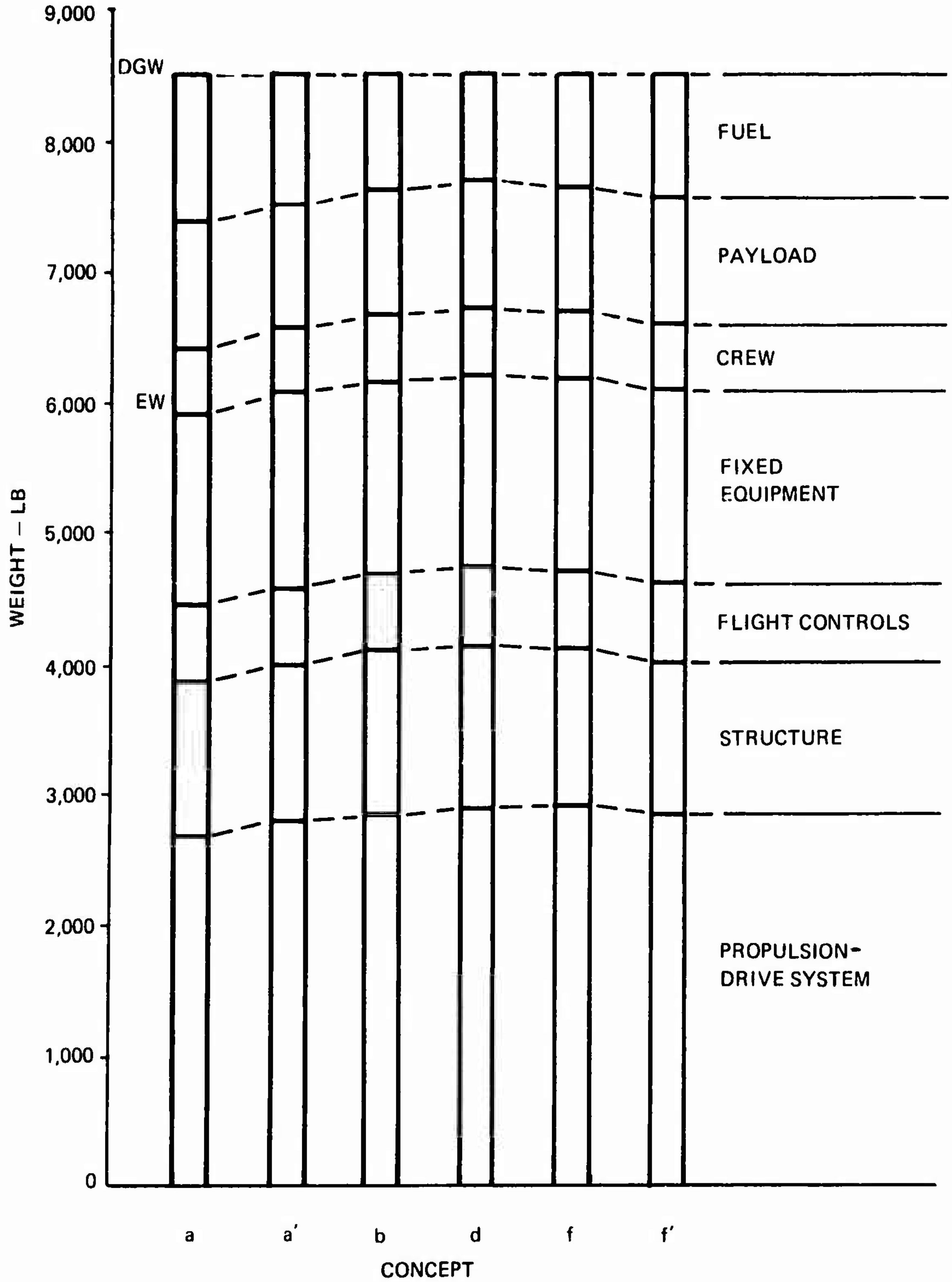

Figure 50. Comparison of 8500-Pound Aircraft Weight Distribution.

Engine manufacturers offer the alternative of front or rear drive even in the small engine sizes considered for these aircraft. Furthermore, they do not indicate any change in performance between the two possible configurations. It is apparent though that the radial blade/vane heights in the compressor and turbine flowpaths are quite small and that the optimum component aerodynamic designs would be at minimum flowpath radii. Through-shaft and bearing requirements necessitated by the front-drive configuration would force the flowpath to larger radii and would have an adverse effect on component and engine performance. Of greater significance, perhaps, would be the possibility of critical speed problems with the relatively long, thin through-shaft, and bearing design speeds in excess of usual design practice. The front-drive configuration really involves some compromises in mechanical and aerodynamic design, and the rear-drive engine would be more attractive from the standpoint of technical risk. A more detailed consideration of the risk factors was considered to be outside the scope of this study, but the possibility of further effort is discussed in the RECOMMENDATIONS section.

In a consideration of the technical risk factors associated with the integrated cooling-IR suppressor systems, the horizontal, front-drive concept was judged to be low risk; the vertical, front-drive concept moderate risk; and the horizontal, direct-drive concept high risk. The horizontal, front-drive concept's plug-type hot metal suppressor and ejector with daisy mixer for plume dilution constituted an IR suppression concept which has been proven in component development programs for other applications.

The vertical engine concept was a variation of the configuration proposed during the initial conceptual design. Although the vane-type hot metal suppressor was a conventional design with attendant low risk, the slotted-duct ejector concept for plume dilution was an untried configuration with a moderate degree of risk attached. The jumbo-slot duct of the horizontal, direct-drive concept, utilizing rotor downwash for exhaust plume dilution, was considered to be an unproven design with a high degree of technical risk.

The differences in transmissions among the various advanced concepts also contributed to slight differences in risk, although component technology was within the state of the art. The spur-gear transmission of the vertical engine concept

offered moderate risk, due to its overall size and arrangement, and particularly the unusual combination of gears and shafts for the accessory and tail rotor drives. The direct-drive triple reduction main transmission of the direct-drive concept with the proposed clutch design introduced a slightly greater technical risk for this concept.

CONFIGURATION SELECTION AND COST CONSIDERATIONS

The configuration selection criteria and relative scores for the advanced concepts, outlined in Appendix B, were reassessed to determine if preliminary design changes in the advanced concepts had impacted the total comparative evaluation. Although cost factors were not considered in the conceptual analyses, qualitative evaluations of aircraft system life-cycle costs were made to determine their influence on the selection of promising vehicle configurations that meet stated system requirements.

Configuration Selection Criteria

The relative scoring of the configuration selection criteria and factors among the three advanced concepts selected for preliminary design, referring to Table B-2 of Appendix B, was quite uniform. With reference to Concepts b and d, the vertical engine concept configured during the conceptual analyses was penalized for its greater length, and for the tail wheel design which was necessitated by the greater length, both in terms of drag under overall system performance and dimensions and transportability under aircraft system design. However, the preliminary design permitted the vertical engine installation to be accomplished within the same aircraft dimensional envelope as the horizontal, front-drive engine arrangement. The change in aircraft dimensions during preliminary design also resulted in the change to the same nose wheel arrangement, rather than the tail wheel. The selection criteria scoring of the vertical, front-drive concept (d) increased from 1160 to 1226 (increases included 45 for Δ drag, 18 for dimensional changes, and 3 for transportability), virtually the same as the horizontal, front-drive concept.

Comparing the empty weights of the advanced concepts in Table 13 to the values generated during conceptual analyses in Table 9, the increased weight of the vertical, front-drive concept and the decreased weight of the horizontal, direct-

drive concept are noted. However, the differences in empty weight are relatively small, and particularly their impact on mission radius capability. Referring to Table B-2 again, the aircraft system weight scoring of the direct-drive concept should increase by 60, and the total score increase to 1169.

Aircraft System Cost

Of the total life-cycle cost of an aircraft system, costs associated with the research, development, test, and engineering (RDTE) phase of the system life cycle comprise only a small percentage of the total. Production costs constitute somewhat less than one-third of the total, while operations and maintenance (O&M) costs constitute two-thirds of the total. Since RDTE costs are a very small percentage of the total life-cycle cost, the technical risk considerations which were discussed above and which have an impact only on RDTE costs become a relatively unimportant cost consideration.

Production costs can be assumed to be a function of aircraft structural weight primarily, and to a lesser degree dependent upon numbers of subsystems and components, and their complexity. Excluding the differences in transmissions and integrated cooling systems among the advanced concepts, the differences in subsystem weight (body group, engine/nacelle group, and armament group) amount to less than one percent of aircraft empty weight. The differences in subsystems and components should provide the major impact on production cost. In this respect, the vertical, front-drive concept with only three transmissions and no bevel meshes between the engine and the main rotor should be superior to the others.

Similarly, differences in subsystems and components should provide the major impact on O&M costs. Although the vertical engine concept and the horizontal, direct-drive concept have the same number of transmissions, the former has fewer bevel meshes. The reduced number of transmissions provides reduced complexity. The vertical, front-drive concept provides the best engine accessibility for maintenance actions. All these factors indicate the superiority of this concept in projected O&M costs, and in overall life-cycle costs.

The advanced concept with vertical, front-drive engines was virtually equal to the highest rated concept on the basis of the configuration selection criteria, and superior to the other advanced concepts in terms of life-cycle system costs. It was recommended as the best of the advanced concepts.

SCALED AIRCRAFT AND ENGINES

Another comparison of interest was that of relative changes in takeoff gross weight of "rubberized aircraft", aircraft scaled up in weight with engines scaled up in power and weight, to perform the same mission and have the same climb capability. "Rubberized" versions of Concepts a to f were generated to meet the following performance requirements:

- o 500 fpm climb capability at 95 percent IRP, 4000 feet, 95°F
- o Design mission with 50-NM radius

Scaling was accomplished at a constant disc loading of 6.5 psf, the same value used in the design of the 8500-pound aircraft. Parametric aircraft gross weight and empty weight were plotted previously in Figure 7. For a selected mission radius of the design mission, Figure 7 illustrated that both design gross weight and empty weight decreased with reduction in disc loading, with a diminishing rate as disc loading approached 6.0 psf. At the lower disc loadings, aircraft weight was primarily dependent upon rotor tip speed. Higher tip speeds, limited by tip Mach number in cruise and/or by rotor noise constraints, resulted in lower weights. Figure 8 demonstrated that the lower disc loading corresponded to reductions in installed shaft horsepower, also. However, Figure 8 showed that the lower disc loadings resulted in larger rotor diameters, as expected. Consequently, disc loading = 6.5 psf and rotor tip speed = 750 ft/sec were selected design values for the scaled aircraft, to minimize takeoff gross weight, empty weight, and installed shaft horsepower, while retaining reasonable rotor diameters.

Table 14 summarizes significant weight, dimensional, and performance parameters for the "rubberized" aircraft. The alternate direct-drive concept with the advanced-technology main transmission is the lightest of the advanced concepts, of course, while the horizontal, front-drive concept is the lightest of the remaining advanced concepts. Of these aircraft scaled to achieve the same vertical rate of climb and mission radius, the desired IR suppression capability could be obtained at a cost of 15 percent in empty weight and 22 percent in installed shaft horsepower. The weights of the "rubberized" aircraft are graphically illustrated in Figure 5.

TABLE 14. AIRCRAFT SYSTEM WEIGHT AND PERFORMANCE COMPARISON FOR SCALED AIRCRAFT

Concept	a Baseline	a' Baseline Current IR Suppressor	b Horizontal Front-Drive Engines	d Vertical Front-Drive Engines	f Horizontal Direct-Drive Engines	f' Advance-Concept Transmission
Takeoff Gross Weight - lb	8695	9220	9858	10061	9923	9566
Weight Empty - lb	6036	6480	6969	7140	7022	6712
Mission Fuel Available - lb	1193	1275	1423	1456	1435	1388
Rotor Diameter - ft (Disc Loading = 6.5 psf)	41.3	42.5	43.9	44.4	44.1	43.3
Hover Power						
Main Rotor Hover Power - shp	883	937	1002	1022	1008	971
Tail Rotor Hover Power - shp	103	113	126	130	127	120
Climb Power						
Main Rotor Hover Power - shp	883	937	1002	1022	1008	971
Tail Rotor Climb Power - shp	118	130	145	149	146	138
Main Rotor Climb Power - shp	86	91	97	99	98	94
Installed Engine Power - shp (Twin Engine, S.L./59°F,IRP)	1669	1809	2032	2073	2000	1928

500 fpm Climb Capability at 95 Percent IRP, 4000 Feet, 95°F
Design Mission with 50-NM Radius

Alternate mission ("Radius Mission") performance was developed for these aircraft sized to accomplish the same design mission, with the resulting payload-range characteristics plotted in Figure 51.

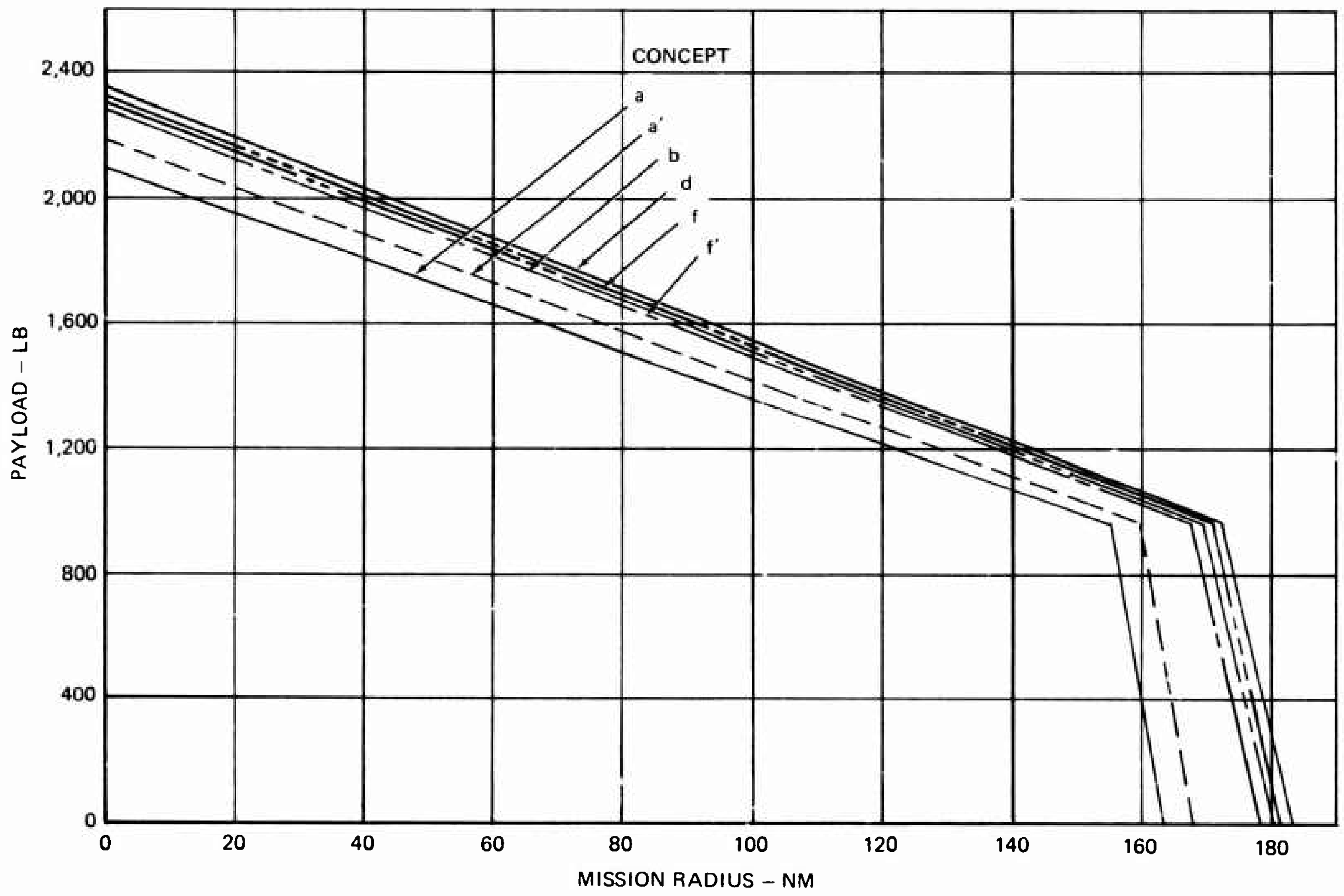

Figure 51. Scaled Aircraft Payload-Range Characteristics for Alternate "Radius Mission".

CONCLUSIONS

This report completes the conceptual analyses and preliminary designs of integrated propulsion-drive system concepts which provide total airflow and power management for a utility helicopter. The following principal conclusions have resulted:

1. The amount of cooling air needed to achieve the desired level of IR signature suppression, together with the requirement for suppression in both hover and cruise operation, dictated a large blower to supply the integrated airflows and an engine exhaust IR device. The weight of the blower-suppressor configuration reduced the fuel weight by a corresponding amount, resulting in a decreased mission radius. Accessory power requirements for the blower reduced rotor power available, resulting in a decreased climb capability. However, the large amounts of cooling air available for IR suppression obviated the need for complex extended-surface heat transfer cooling panels. Instead, hot metal suppressor concepts can utilize large louvers for cooling air, resulting in a more cost-effective design.

   The baseline helicopter with a current IR suppressor design offered substantially improved range and climb capability compared to the advanced concepts, but less than the desired IR suppression capability.

2. The configuration with vertical, front-drive engines was recommended as the best of the advanced concepts. In terms of the configuration selection criteria established for the study, this concept was essentially equal to the best of the concepts. Qualitative evaluations indicated that it was the best in terms of aircraft system life-cycle costs. Operations and maintenance costs typically constitute a large percentage of life-cycle costs. The vertical engine concept offered the lowest number of transmissions and bevel-gear meshes and the best engine accessibility, which should have the greatest impact on O&M costs.

3. The baseline helicopter and the aircraft incorporating advanced propulsion integration concepts were scaled to achieve 500-fpm climb capability and 50-NM

radius for the primary design mission. The lightest of the advanced aircraft was the configuration with horizontal, front-drive engines, with an empty weight 15 percent greater than the baseline and with 22 percent more installed shaft horsepower.

RECOMMENDATIONS

For the vertical, front-drive concept, selected as the best of the advanced concepts, recommendations are made for detailed investigations of propulsion-related subsystems. Aerodynamic performance of the engine plenum inlets, the particle separator scavenge system, and the exhaust plume dilution configuration should be evaluated. Investigations should be initiated to optimize the main transmission design and the oil cooling arrangement, particularly in conjunction with the technology introduced with the advanced-concept transmissions.

System requirements which established certain ground rules for this program limited the scope of the effort, and suggestions of other potentially attractive concepts are made.

1. Technical risk discussion in the section on DESIGN ANALYSIS included considerations of risk inherent in the selection of front- versus rear-drive engines. It was pointed out that in small advanced-technology engines, the through-shaft for a front-drive configuration introduced risk factors in the mechanical design, both in shaft critical speed and in bearing design, and also introduced compromises in component and engine performance. These are factors which indicate the desirability, and possibly the necessity, of the rear-drive configuration. Previous discussion about the advanced-concept direct-drive transmission indicated that it would be an attractive design arrangement in conjunction with the rear-drive engine. One recommendation for further effort would be to investigate the front- versus rear-drive engine configuration selection in conjunction with the advanced-concept transmission.

   This study necessarily gave only superficial consideration to engine starting, which could be a critical subsystem requirement for small engines in small helicopters. Sufficient work was accomplished to indicate that battery starting would probably be a viable concept. However, it is recommended that these aspects of engine drive system-airframe integration would be worthy of further consideration.

2. System requirements established the desired level of hot metal suppression and exhaust plume dilution for

this program, and the design results have indicated that the plume dilution requirement was the basis for sizing the integrated airflow blower and its horsepower demand. Atmospheric attenuation has a very strong impact on the exhaust plume signature, so in conjunction with IR missile capability, it could prove reasonable to reduce the plume dilution requirement. This would, in turn, reduce blower accessory power requirements and blower weight. It also opens the door to other possible IR suppressor concepts, utilizing ejector action and/or a ram inlet scoop to charge the suppressor with atmospheric air and further reduce accessory power requirements. It is recommended that the desirable level of hot metal and exhaust plume IR suppression be the subject of further study, to minimize system weight and accessory power requirements.

3. System requirements defined a simple-cycle advanced turboshaft engine, with the alternatives of front or rear drive and horizontal or vertical mounting, to be used in the study. Other viable propulsion configurations could prove beneficial in these integrated propulsion-drive system concepts, such as the following arrangements:

   - The gas generator and power turbine could be separated, with the power turbine and engine transmission integrated into a single configuration and gas-coupled to the gas generator. The integrated power turbine-engine transmission would be beneficial from the viewpoint of reduced bearing requirements and balanced axial thrust loads.

   - The gas-coupled arrangement described above could employ a single power turbine in conjunction with two gas generators to further simplify the propulsion system. The single power turbine, particularly with a partial admission nozzle design for optimum part-power performance, would provide a substantial performance improvement for extended cruise operation.

   - Regenerative turboshaft engines would perform part of the IR suppression task by reducing

exhaust plume temperatures, thus alleviating the requirements for external dilution airflow and reducing accessory power requirements by 50 percent. Discussion on page 8 of Reference 7 covers the improved vulnerability aspects of the regenerative engines, which also provide improved performance, particularly in part-power operation.

It is recommended that these propulsion concepts be considered as viable alternatives to the simple-cycle turboshaft engines for further propulsion integration studies.

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APPENDIX A
INTEGRATED AIRFLOW REQUIREMENTS

The external airflows which were integrated in the six advanced propulsion system concepts included the following:

- Engine inlet airflow.
- Inlet separator scavenge flow.
- Engine compartment cooling air.
- Drive train compartment cooling air.
- Transmission oil cooling airflow.
- IR suppression airflow, hot metal, and plume dilution.

Figure A-1 illustrates schematically the integrated airflows.

Table A-1 has been developed to provide the calculated values of significant parameters at various stages of the flow mixing processes. The design point selected for the calculation was engine operation at intermediate rated power, 4000 feet, 95°F ambient conditions.

Current IR Suppressor Design

The impact on weight and performance of the baseline aircraft due to the installation of a current IR suppressor design has been included in the study results. The thermodynamic mixing processes of this configuration were generally quite similar to those of the advanced integration concepts. A smaller, hydraulic-powered blower was used to provide cooling air for hot metal suppression and exhaust plume dilution, and a ram scoop provided additional cooling air through ejector action of the engine exhaust flow. The hydraulic blower, augmented by ambient air flowing through the scoop inlet, resulted in a limited suppression of the IR signature in hover, although the ram scoop should offer improved suppression capability in cruise flight.

Calculated values of temperature and flow parameters for the current IR suppressor design also are tabulated in Table A-1.

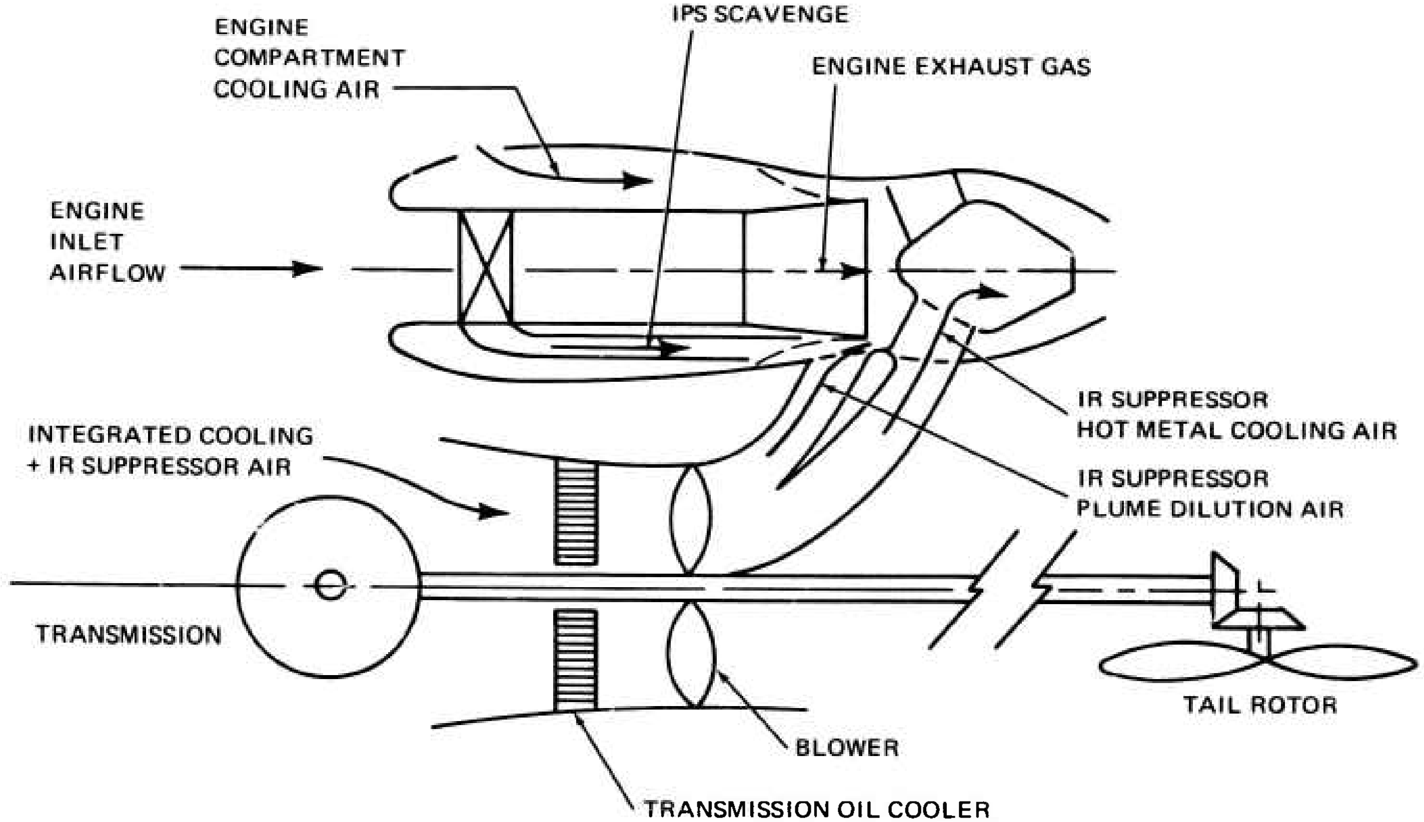

Figure A-1. Schematic Drawing of Integrated Airflows.

TABLE A-1. INTEGRATED AIRFLOW REQUIREMENTS (DESIGN POINT: 4000 Ft, 95°F, IRP)

Parameter		Units	Advanced Integration Concepts	Current IR Suppressor Design
Engine Exhaust:	Gas Flow	lb/sec	4.04	4.04
	Temperature	°F	1100.	1100.
IPS Scavenge:	Airflow	lb/sec	0.74	0.74
	Temperature	°F	140.	140.
Engine Compartment:	Airflow	lb/sec	1.23	1.23
	Temperature	°F	140.	140.
Transmission Oil Cooling:	Transmission Losses	percent	2.6	
	Installed IRP	SHP	1162.	
	Transmission Losses	SHP	30.2	
	Transmission Losses	BTU/min	1285.	
	Blower Airflow	lb/sec	17.8	1.0
	Cooling Air ΔT	°F	5.1	
	Blower Pressure Rise	in. water	20.	20.
	Blower ΔT	°F	14.8	14.8
Engine Exhaust Gas Flow		lb/sec	4.04	4.04
IPS + Compartment Airflow		lb/sec	1.97	1.97
Plume Dilution Airflow		lb/sec	5.90	0.90
Mixed Flow - Suppressor Inlet:	Air/Gas Flow	lb/sec	11.91	6.91
	Temperature	°F	470.	726.
Hot Metal Cooling:	Air/Gas Temperature	°F	470.	726.
	Surface Temperature	°F	200.	275.
	Cooling Air Temperature	°F	115.	110.
	Required Effectiveness*		0.76	0.73
	Hot Metal Cooling Flow	lb/sec	3.00	1.0
	Suppressor Surface Area	ft^2	12.0	9.0
	Cooling Flow/Area	$lb/sec/ft^2$	0.25	0.11
	Predicted Effectiveness*		0.85	0.76
Mixed Flow - Suppressor Exit:	Air/Gas Flow	lb/sec	14.91	7.91
	Temperature	°F	400.	642.

$$\text{*Effectiveness} = \frac{\text{Air/Gas Temperature} - \text{Surface Temperature}}{\text{Air/Gas Temperature} - \text{Cooling Air Temperature}}$$

APPENDIX B
ADVANCED AIRCRAFT CONFIGURATION SELECTION CRITERIA

Conceptual propulsion system designs were completed for six engine/transmission/airframe integrated design concepts which provide total airflow and power management for a utility transport helicopter. Comparative analyses were conducted for these six advanced concepts and for a baseline aircraft, to evaluate aircraft system performance, system weight, system complexity, technical risk, control requirements, and aircraft system design. The factors considered under the heading of each of these evaluation criteria are listed below:

- Overall System Performance (DGW = Constant)

    Δ Range

    Rotor Horsepower

    Rate of Climb

    Δ Drag

    Momentum Drag (Cooling Airflow/External Flow Requirements)

    Internal Flow Losses

- Aircraft System Weight

    Empty Weight

- System Complexity

    Number of Subsystems/Components

    Number of Transmissions/Number of Bevel Gear Meshes

    Reliability and Maintainability

    Simplicity/Producibility

- Technical Risk

    Component/Subsystem Development

- Control Requirements

    Dynamic System Compatibility

    Subsystem Control Requirements

- o Aircraft System Design

    Dimension/Configuration Changes

        Impact on Transportability

    Engine Installation

        Inlet Ingestion Susceptibility

        Inlet Flow Uniformity

        Front/Rear Drive Impact on Engine Configuration

        Noise - Proximity to Cockpit/Cabin

    Vulnerability/Survivability Considerations

    IR Suppressor On-Off Capability

    Safety/HFE - Location of Engine Inlet/Exhaust
    Tail Rotor Vs. Louvers

The weighting factors for each of the evaluation criteria, to determine their importance in relationship to each other for purposes of the comparative evaluations, are developed in Table B-1. Each of the evaluation criteria is compared with every other one in turn, with the criterion of greater importance (in the opinion of the evaluator) being scored 1 and the criterion of lesser importance being scored 0. The weighting factors are the resulting sums.

Scoring of each of the factors considered under the various criteria of aircraft system performance, system weight, system complexity, control requirements, and aircraft system design was based upon the performance levels tabulated below:

SCORE	PERFORMANCE LEVEL
5	Excellent (exceeds all requirements)
4	Good (exceeds minimum requirements)
3	Adequate (generally meets minimum requirements)
2	Weak (does not meet minimum requirements)
1	Poor (makes omission in a major area)
0	Inadequate (fails to respond to requirements in major areas)

TABLE B-1. CONFIGURATION SELECTION WEIGHTING FACTORS

Evaluation Criteria	Relative Importance					Weighting Factor
Overall System Performance	1 1 1 1 1					5
Aircraft System Weight	0	0 1 1 1				3
System Complexity	0	1	1 1 1			4
Technical Risk	0	0	0	1 0		1
Control Requirements	0	0	0	1	0	1
Aircraft System Design	0	1	0	1	1	3

Technical risk scoring was determined as follows:

SCORE	TECHNICAL RISK
5	Substantially "O" risk (technology is in use on production aircraft, and needs no modification as used herein)
4	Insignificant (items of similar technology in production, highly reliable, and only minor changes required as used herein)
3	Low (uses proven improvements from component programs; potential problem solutions are well understood)
2	Moderate (similar performance has been demonstrated in component test, and developmental areas are within "state-of-the-art")
1	High (requires breakthroughs in minor areas, and probability of unforeseen developmental problems is high)
0	Critical (would require several major breakthroughs with high probability of many unforeseen problems)

The comparative evaluations are quantified in Table B-2. Total possible score for each of the evaluation criteria and each factor is tabulated in the first column of the table. The sum of the individual scores for each evaluation criterion is in proportion to the weighting factors defined above in Table B-1.

Table 7 provides the weight and performance data to substantiate the scoring of aircraft system performance and system weight. Tables B-3 and B-4 are brief summaries of the evaluations of system complexity and system design which are reflected in those scores.

The three advanced concepts selected for the preliminary design phase of the study were Concepts b, d and f-alternate - the horizontal, front-drive engine concept; the vertical, front-drive concept; and the horizontal, direct-drive concept.

TABLE B-2. AIRCRAFT CONFIGURATION SELECTION CRITERIA

Selection Criteria and Factors	Relative Value of Each Evaluation Factor	Concept Scores a Baseline	b Horizontal Front Drive	c Fan-in-Fuselage	d Vertical Front Drive	e Horizontal Rear Drive	f Horizontal Direct Dr.	g Vertical Rear Drive
Overall System Performance (DGW = Constant)	100	500	315	270	210	205	345	305
△ Range	30	150	90	60	90	90	90	90
Rotor Power Available	15	75	30	60	15	0	60	45
Rate of Climb	25	125	50	100	25	0	100	75
△ Drag	15	75	75	15	30	60	45	45
Momentum Drag (Cooling Air/External Flow Requirements)	10	50	50	20	30	40	40	40
Internal Flow Losses	5	25	20	15	20	15	10	10
Aircraft System Weight	60	300	240	120	240	180	180	180
Empty Weight								
System Complexity	80	270	305	215	370	150	290	240
Number Subsystems/Components	25	100	125	100	125	25	100	75
Number Transmissions/Bevel Gear Meshes	15	45	45	60	75	45	60	75
Reliability and Maintainability	25	50	75	25	125	50	100	75
Simplicity and Producibility	15	75	60	30	45	30	30	15
Technical Risk	20	100	60	40	60	20	20	20
Component/Subsystem Development								
Control Requirements	20	100	70	25	100	55	85	85
Dynamic System Compatibility	15	75	45	15	75	30	60	60
Subsystem Control Requirements	5	25	25	10	25	25	25	25
Aircraft System Design	60	204	240	234	180	192	189	237
Dimension/Configuration Changes	9	36	36	27	18	36	18	45
Impact on Transportability	3	12	12	15	9	12	9	12
Engine Installation								
Inlet Ingestion Susceptibility	3	15	15	15	12	15	9	6
Inlet Flow Uniformity	3	9	9	9	3	15	12	6
Front/Rear Drive Impact on Engine Configuration	3	9	9	9	9	12	15	15
Noise - Proximity to Cockpit/Cabin	3	15	15	15	9	12	6	9
Vulnerability/Survivability Considerations	12	0	36	48	48	36	24	60
IR Suppressor On-Off Capability	6	30	30	30	30	0	30	30
Safety/HFE - Location of Engine Inlet/Exhaust	12	60	60	36	24	36	48	36
Tail Rotor vs. Louvers	6	18	18	30	18	18	18	18
Totals	*340	1474	1230	904	1160	802	1109	1067

* Total Possible Score for a Concept = 340 x 5 = 1700

TABLE B-3. CONCEPT EVALUATION - FACTORS IN SYSTEM COMPLEXITY

Concepts	a Baseline	b Horizontal Front Drive	c Fan-in-Fuselage	d Vertical Front Drive	e Horizontal Rear Drive	f Horizontal Direct Drive	g Vertical Rear Drive
Subsystems/Components							
Installed Engine	Integral IPS/Blower	Integral IPS Ejector Scavenge	Integral IPS/Blower	Integral IPS Ejector Scavenge	Integral IPS/Blower	Airframe IPS Ejector Scavenge Engine Sponsons	Integral IPS/Blower
Transmissions							
Engine (2)	Bevel	Bevel	Bevel	None	Bevel	None	None
Main	Bevel	Bevel	Bevel Complex Main Xmsn.	Spur/Planetary Large Main Xmsn.	Bevel	Bevel	Spur/Planetary Large Main Xmsn.
Intermediate	Bevel	Bevel	None	Bevel	Bevel	Bevel	Bevel
Tail Rotor	Bevel	Bevel	None	Bevel	Bevel	Bevel	Bevel
Accessory Gearboxes (2)	Fore/Aft	2 Fore AGB's	Fore/Aft	Fore/Aft	2 Fore AGB's	2 Fore AGB's	Fore/Aft
Xmsn Oil Cooler/Blower	Integral	None	None	None	None	None	None
Antitorque Control	Tail Rotor	Tail Rotor	Variable Pitch Fan + Louvers	Tail Rotor	Tail Rotor	Tail Rotor	Tail Rotor
IR Suppression	None	Integral Blower/ Tail Rotor Shaft Plug-Type Suppressor	None	Vertical Mounted Blower Ejector/Vane IRS	Two Element Fan Plug-Type Suppressor	Integral Blower/ Tail Rotor Shaft Plug-Type + Jumbo- Slot IRS	Integral Blower/ Tail Rotor Shaft Cooled Tailpipe + Jumbo-Slot IRS
Transmissions/Bevel Meshes	5 Xmsns/6 Bevels	5 Xmsns/6 Bevels	3 Xmsns/3 Bevels	3 Xmsns/3 Bevels	5 Xmsns/6 Bevels	3 Xmsns/4 Bevels	3 Xmsns/3 Bevels
Changes in R&M							
Reductions -		2 IPS Blowers (Erosion) Oil Cooler Blower	Tail Rotor Intermediate/Tail Rotor Xmsns.	2 IPS Blowers 2 Engine Xmsns. 2 Bevel Meshes Oil Cooler Blower	Oil Cooler Blower	2 IPS Blowers Oil Cooler Blower 2 Engine Xmsns.	Oil Cooler Blower 2 Engine Xmsns. 2 Bevel Meshes
Additions -		IRS Blower	Variable-Pitch Fan Louvers (R of Fan Poor Due to Inlet Location)	IRS Blower Poor Blower Accessibility	Two-Element Fan	IRS Blower	IRS Blower Poor Engine Accessibility
Simplicity/Producibility							
Subsystem Changes		IRS Blower/Scroll IR Plug Suppressor	Variable-Pitch Fan + Louver System Complex Main Xmsn.	IRS Blower/Scroll IR Vane Suppressor Large Main Xmsn.	IRS Fan IR Plug Suppressor	IRS Blower, Plenum, Jumbo-Slot Duct Plug Suppressor	IRS Blower, Plenum, Jumbo-Slot Duct Cooled Tailpipe Large Main Xmsn.

TABLE B-4. CONCEPT EVALUATION - AIRCRAFT SYSTEM DESIGN CHANGES FROM BASELINE

Concepts	b Horizontal Front Drive	c Fan-in-Fuselage	d Vertical Front Drive	e Horizontal Rear Drive	f Horizontal Direct Drive	g Vertical Rear Drive
<u>Dimension/Configuration Changes</u>	-	Shorter, Twin Tail Exceeds Transportability Envelope	Longer Due to Engine Installation	-	Engine Sponsons Wider Envelope	Smaller Envelope Buried Engine
Transportability	-	Remove Tail Fins Only	Impact of Tail Wheel	-	Sponson Tip Removed For Transportability	-
<u>Engine Installation</u> Inlet Ingestion	-	-	Satisfactory, Rotor Upwash Near Fuselage	-	Worse Due to Outboard Location	Bad Location on Side of Fuselage
Inlet Flow Uniformity	-	-	Plenum Inlet/Xmsn. Result in Poor Inlet Flow	Clean Inlet	Clean Inlet But Flow Turns	Plenum Inlet + Turn
Front/Rear Drive	-	-	-	Rear Drive	Rear Drive Without Angle Xmsn.	Rear Drive Without Angle Xmsn.
Noise	-	-	Higher Noise Level in Cabin	Slightly Higher Noise Level in Cockpit	Higher Noise Level in Cockpit/Cabin	Higher Noise Level in Cabin
<u>Vulnerability/Survivability</u>	Worse - Size of Blower for Oil Cooling, Proximity of AGB's	Better - Same Fore/Aft AGB Location Buried Antitorque Fan. However, Oil Cooler Vulnerability Increases.	Better - Buried Engines, No Engine Xmsns. More Vulnerable Blower. Same Fore/Aft AGB Location.	Worse - Size of Blower for Oil Cooling, Proximity of AGB's	Worse - Vulnerability of Engines, Proximity of AGB's	Better - Buried Engines, Same Fore/Aft AGB Location But Increased Blower Vulnerability.
<u>IR Suppressor On-Off Capability</u>	Yes - Vent Blower	No IRS ΔPerformance as Such	Yes	No	Yes	Yes
<u>Safety/HFE</u> Inlet/Exhaust	-	Bad Fan Inlet Location	Very Bad Exhaust Location	Poor Exhaust Location	Exhaust Somewhat Worse Than Baseline	Poor Inlet Location Exhaust Somewhat Worse Than Baseline
Tail Rotor vs. Louvers	-	Better	-	-	-	-

APPENDIX C

GROUP WEIGHT STATEMENT

MIL-STD-1374 PART I

Name D. Pritchard

Date

Page 1

Model

Report

GROUP WEIGHT STATEMENT

AIRCRAFT

(INCLUDING ROTORCRAFT)

ESTIMATED - ~~CALCULATED~~ - ~~ACTUAL~~

(Cross Out Those Not Applicable)

Conventional Aircraft - No IR Suppressor
- IR Suppressor Kit

Advanced Helicopters - 3 Configurations

CONTRACT NO. DAAJ02-74-C-0043

AIRCRAFT, GOVERNMENT NO.

AIRCRAFT, CONTRACTOR NO.

MANUFACTURED BY Boeing Vertol Company

ENGINE		MAIN	AUX
	MANUFACTURED BY	Advanced-	
	MODEL	Technology	
	NO.	Turboshaft	
	TYPE	Engine	

PAGES REMOVED	PAGE NO.

MIL STD 1374 PART I

GROUP WEIGHT STATEMENT
WEIGHT EMPTY

Name ______

Date ______

Page 2

Model ______

No.	Item	Conventional Aircraft - Concept a: No IR Suppressor		Conventional Aircraft - Concept a: IR Suppressor Kit		Advanced Helicopters: Concept b		Advanced Helicopters: Concept d		Advanced Helicopters: Concept f	
1	WING GROUP										
2	BASIC STRUCTURE - CENTER SECTION										
3	- INTERMEDIATE PANEL										
4	- OUTER PANEL										
5	- GLOVE										
6	SECONDARY STRUCTURE (incl. Wing Fold Weight Lbs.)										
7	AILERONS (incl. Balance Weight Lbs.)										
8	FLAPS - TRAILING EDGE										
9	- LEADING EDGE										
10	SLATS										
11	SPOILERS										
12											
13											
14	ROTOR GROUP		888		888		888		888		888
15	BLADE ASSEMBLY	492		492		492		492		492	
16	HUB & HINGE (incl. Blade Fold Weight Lbs.)	396		396		96		396		396	
17											
18											
19	TAIL GROUP		15		153		153		153		153
20	BASIC & SECONDARY STRUCT. - STABILIZER	38		38		38		38		38	
21	- FIN (incl. Dorsal)	75		75		75		75		75	
22	VENTRAL										
23	ELEVATOR (incl. Balance Weight Lbs.)										
24	RUDDERS (incl. Balance Weight Lbs.)										
25	TAIL ROTOR - BLADES	4		40		4		40		40	
26	- HUB & HINGE										
27											
28	BODY GROUP		[illegible]		791		[illegible]		[illegible]		809
29	BASIC STRUCTURE - FUSELAGE or HULL										
30	- BOOMS										
31	SECONDARY STRUCTURE - FUSELAGE or HULL										
32	- BOOMS										
33	- SPEEDBRAKES										
34	- DOORS, RAMPS, PANELS, & MISC										
35											
36											
37	ALIGHTING GEAR GROUP (Type Tricycle Fixed)		45		245		245		245		245
38	LOCATION / Running Gear* / Arrest Gear* / Structure / Controls										
39	MAIN GEAR FUSELAGE	187		187		187		187		187	
40	NOSE GEAR FUSELAGE	49		49		49		49		49	
41	TAIL BUMPER-BOOM	9		9		9		9		9	
42											
43											
44											
45	ENGINE SECTION or NACELLE GROUP		[illegible]		[illegible]		94		153		167
46	BODY - INTERNAL										
47	- EXTERNAL										
48	WING - INBOARD										
49	- OUTBOARD										
50											
51											
52	AIR INDUCTION SYSTEM										
53	DOORS, PANELS, & MISC										
54											
55											
56											
57	TOTAL STRUCTURE (To Be Brought Forward)		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]

*Change to Floats & Struts for Water Type Gear

MIL-STD-1374 PART I

GROUP WEIGHT STATEMENT
WEIGHT EMPTY

Name ____________
Date ____________

Page 3
Model ____________
Report ____________

				CONVENTIONAL AIRCRAFT-CONCEPT a				ADVANCED HELICOPTERS					
				No IR Suppressor		IR Suppressor Fit		Concept b		Concept d		Concept f	
1	PROPULSION GROUP	Auxiliary	Main		16[illegible]5		1[illegible]		18[illegible]1		187[illegible]		1[illegible]6[illegible]
2	ENGINE INSTALLATION			[illegible]		[illegible]		408		4[illegible]8		4[illegible]8	
3													
4	ACCESSORY GEAR BOXES & DRIVE												
5	INTEGRATED AIRFLOW POWER [illegible] SYSTEM							9[illegible]		[illegible]		53	
6	EXHAUST SYSTEM/IR SUPPRESSOR			5		1[illegible]		1[illegible]0		7[illegible]		136	
7	ENGINE COOLING												
8	~~XXXXXXXX~~ INLET PARTICLE SEPARATOR											[illegible]	
9	ENGINE CONTROL			17		17		16		1[illegible]		1[illegible]	
10	STARTING SYSTEM			1[illegible]		14[illegible]		1[illegible]		1[illegible]		13[illegible]	
11	PROPELLER INSTALLATION												
12	SMOKE ABATEMENT												
13	LUBRICATING SYSTEM			1		1		1		1		1	
14	FUEL SYSTEM			1[illegible]		147		1[illegible]		1[illegible]		125	
15	TANKS PROTECTED												
16	UNPROTECTED												
17	PLUMBING etc												
18	DRIVE SYSTEM			9[illegible]		[illegible]		921		1[illegible]1		971	
19	GEAR BOXES LUB SY & ROTOR BRK												
20	TRANSMISSION DRIVE												
21	ROTOR SHAFTS												
22	JET DRIVE												
23													
24	FLIGHT CONTROLS GROUP				59[illegible]		59[illegible]		592		592		592
25	COCKPIT CONTROLS (Auto pilot Lbs)			4[illegible]		48		48		48		48	
26	SYSTEMS CONTROLS - INCLUDING HYDRAULIC BOOST			5[illegible]		254		254		254		254	
27	ROTATING NON-ROTATING CONTROLS			[illegible]55		255		255		25[illegible]		255	
28	SAS			5		35		35		[illegible]5		[illegible]5	
29	AUXILIARY POWER PLANT GROUP												
30	INSTRUMENTS GROUP				14[illegible]		1[illegible]		142		142		142
31	HYDRAULIC & PNEUMATIC GROUP				5[illegible]		5[illegible]		5[illegible]		5[illegible]		5[illegible]
32													
33	ELECTRICAL GROUP				2[illegible]		2[illegible]		[illegible]		200		200
34													
35	AVIONICS GROUP				4[illegible]6		[illegible]66		4[illegible]6		466		466
36	EQUIPMENT			[illegible]		[illegible]5[illegible]		[illegible]		35[illegible]		35[illegible]	
37	INSTALLATION			11		11[illegible]		11[illegible]		116		116	
38													
39	ARMAMENT GROUP (incl Passive Prot Lbs)				45		45		115		62		62
40	FURNISHINGS & EQUIPMENT GROUP				468		468		46[illegible]		468		468
41	ACCOMMODATION FOR PERSONNEL			31[illegible]		[illegible]1[illegible]		[illegible]		312		31[illegible]	
42	MISCELLANEOUS EQUIPMENT			57		57		57		57		57	
43	FURNISHINGS			4[illegible]		4		4[illegible]		4[illegible]		4[illegible]	
44	EMERGENCY EQUIPMENT			56		56		56		56		56	
45													
46	AIR CONDITIONING GROUP				4[illegible]		40		40		40		4[illegible]
47	ANTI-ICING GROUP				[illegible]		[illegible]6		3[illegible]		36		36
48													
49	PHOTOGRAPHIC GROUP												
50													
51	LOAD & HANDLING GROUP				6		[illegible]6		[illegible]6		36		36
52	AIRCRAFT HANDLING												
53	LOAD HANDLING												
54													
55	MANUFACTURING VARIATION												
56	TOTAL FROM PAGE 2				[illegible]		2155		1[illegible]		227[illegible]		2262
57	WEIGHT EMPTY				[illegible]		[illegible]7		[illegible]1[illegible]6		62[illegible]		6216

MIL-STD-1374 PART I

GROUP WEIGHT STATEMENT
USEFUL LOAD AND GROSS WEIGHT

Page 4
Model
Report
Name
Date

No.	Item				Conventional Aircraft Concept a: No IR Suppr.	Conventional Aircraft Concept a: IR Suppr. Kit	Advanced Helicopters: Concept b	Advanced Helicopters: Concept d	Advanced Helicopters: Concept f
1	LOAD CONDITION				TROOP	TROOP	TROOP	TROOP	TROOP
2					ASSAULT	ASSAULT	ASSAULT	ASSAULT	ASSAULT
3	CREW (No 2)				470	470	470	470	470
4	PASSENGERS (No 4)				960	960	960	960	960
5	FUEL	Location	Type	Gals.					
6	UNUSABLE				10	10	10	10	10
7	INTERNAL	FUSELAGE	JP4/5		1107	964	868	802	818
8									
9									
10									
11	EXTERNAL								
12									
13									
14	OIL								
15	TRAPPED								
16	ENGINE				26	26	26	26	26
17									
18	FUEL TANKS (Location)								
19	WATER INJECTION FLUID (Gals.)								
20									
21	BAGGAGE								
22	CARGO								
23									
24	GUN INSTALLATIONS								
25	GUNS / Location	Fix or Flex	Quantity	Caliber					
26									
27									
28	AMMO								
29									
30									
* 31	SUPP'TS								
** 32	WEAPONS INSTALL (Incl Submarine Detection Expendables)								
33									
34									
35									
36									
37									
38									
39									
40									
41									
42									
43									
44									
45									
46	EQUIPMENT								
47									
48	SURVIVAL KITS & LIFE RAFTS								
49									
50	OXYGEN								
51									
52									
53									
54									
55	TOTAL USEFUL LOAD				2573	2430	[illegible]	2268	2284
56	WEIGHT EMPTY				5927	6070	6166	6232	6216
57	GROSS WEIGHT				8500	8500	8500	8500	[illegible]

*If Removable and Specified as Useful Load

**List Stores, Missiles, Sonobuoys, etc. Followed by Racks, Launchers, Chutes, etc. Not Part of Weight Empty
List Identification, Location, and Quantity for All Items Shown Including Installation

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

AGB	Accessory gearbox
APU	Auxiliary power unit
C_T	Main rotor thrust coefficient, dimensionless
DGW	Design gross weight, lb
ECU	Environmental conditioning unit (cooling/heating)
EW	Empty weight, lb
f_e	Equivalent flat plate drag, ft^2
HOGE	Hover out-of-ground effect
IPS	Inlet particle separator
IR	Infrared (signature)
IRP	Intermediate rated power (30-minute engine rating), shp
$\dot{M}$	Mass airflow rate (Figure 27), lb/sec
MCP	Maximum continuous power, shp
PL	Payload, lb
SFC	Specific fuel consumption=fuel flow (lb/hr)/shaft horsepower, lb/hr/shp
V	Aircraft flight speed (Figure 27), ft/sec
V_{EXIT}	IR suppressor exit flow velocity (Figure 27), ft/sec
VRC	Vertical rate-of-climb, fpm
σ	Main rotor blade solidity, dimensionless

SUBSCRIPTS (Figure 27)

CO	Drive system/IR suppression cooling flow
COMP	Engine compartment cooling airflow
DIL	IR suppressor ram inlet dilution airflow
ENG	Engine airflow
EXIT	IR suppressor exit flow
IPS	Inlet particle separator scavenge airflow